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Evaluating the Superpave Option in Unified Facilities Guide Specification 32-12-15.13, Hot Mix Asphalt Airfield Paving

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Abstract

This report presents results from a field study to compare the density of asphalt concrete specimens compacted using the Marshall apparatus to the density of specimens compacted using the Superpave gyratory compactor (SGC). The purpose of the study was to determine if using a new alternative construction specification based on compaction with the SGC would produce a different density than the traditional specification based on compaction with the Marshall apparatus. In addition, laboratory tests to indicate asphalt mixture rutting potential were performed to develop guidance for using new methods to assess mixture quality. Six paving mixtures were sampled to compact specimens using 75 blows of the manual Marshall hammer and 75 gyrations of the SGC. Three of the mixtures had higher air voids contents when compacted with the SGC. Two had nearly equal air voids content, and one had lower air voids content. The standard deviation of air voids content for a group of specimens compacted using the SGC was typically less than half of that for specimens compacted using the manual Marshall hammer. Using the SGC to prepare specimens for quality control and quality assurance is not expected to change the payment to a contractor for a given quality of work when using the method described in UFGS 32-12-15, and is expected to produce adequate mixtures when designed by the alternative specification allowing its use.

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Preface

This study was conducted for the U.S. Air Force Civil Engineering Center (AFCEC), located in Tyndall Air Force Base, FL. Dr. Craig A. Rutland from AFCEC provided guidance during the project.

The work was performed by the Airfields and Pavements Branch (GM-A) of the Engineering Systems and Materials Division (GM), U.S. Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL), At the time of the publication, Dr. Gary L. Anderton was Chief, CEERD-GM-A; Dr. Larry N. Lynch was Chief, CEERD-GM; and Dr. David A. Horner, CEERD-GV-T, was the Technical Director for Force Projection and Maneuver Support. The Deputy Director of ERDC-GSL was Dr. William P. Grogan and the Director was Dr. David W. Pittman.

COL Jeffrey R. Eckstein was the Commander of ERDC and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
inches	2.54	millimeters
kips (force) per square inch	6.894757	megapascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms

1 Introduction

1.1 Background

In the 1990s, the Federal Highway Administration introduced the Superior Performing Pavements (Superpave) mixture design method for asphalt concrete pavements. The method was introduced to improve the quality of highway pavements by enhancing material properties and by better simulating field compaction using a Superpave Gyratory Compactor (SGC). The Superpave method currently is used in nearly every state in the United States to design asphalt mixtures for highway pavements. It is the most common method used by asphalt paving contractors and testing laboratories.

Historically, airfield asphalt paving mixtures have been designed using the Marshall method. This method was introduced for airfield pavements in the 1940s. Modifications to the procedure over time have improved its ability to produce mixture proportions suitable for airfield pavements. The current version of the Marshall procedure is specified for designing airfield pavements in Unified Facilities Guide Specification (UFGS) 32-12-15.13, *Hot mix asphalt airfield paving* (Headquarters, Departments of the Army, Navy, and Air Force 2013).

In 2011 a Superpave option was added to UFGS 32-12-15.13 to allow the use of the SGC to compact mixture specimens instead of using the Marshall hammer. The option specified the compaction effort for designing high-quality mixtures to be 75 gyrations in the SGC. Since its inclusion in the UFGS, the Superpave option rarely has been selected for designing hot mix asphalt (HMA) airfield pavements.

1.2 Previous work

A major factor in the ability of the Superpave option of the UFGS specification to produce quality asphalt mixtures is the specified compaction effort for design. Increasing the compaction effort reduces the design asphalt content because the design is based on a target air voids content of 4.0 percent. Rushing (2011) performed a laboratory study using 52 asphalt mixtures to determine an appropriate compaction effort for design. For each of the mixtures, the number of gyrations in the SGC was measured that produced equivalent density to the 75-blow Marshall design. Results from the study indicated the average number of gyrations producing an equivalent density was 69 and the standard deviation was 25. Although a wide range of values existed, 70 gyrations was recommended as an alternative to the 75-blow Marshall method. The compaction effort was adjusted to 75 gyrations in the UFGS to avoid confusion in the numbers associated with the compaction effort. Adding five additional gyrations (to match 75 blows of the Marshall hammer) during design causes little difference in the design binder content.

All of the guidance for compacting airfield mixtures using the SGC has been based on laboratory-produced mixtures. Quality control and quality assurance protocols specified in the UFGS require laboratory compaction of plant-produced mixtures. The percent payment that a contractor receives is based upon these results. The ability of the SGC compaction requirement (specified gyrations) to match field compaction from plant-produce mixture is unknown. In addition, the variability of SGC compaction is not documented for airfield mixtures. Additional research is needed to validate that 75 gyrations is an appropriate compaction effort for designing and testing HMA for airfields and to determine the impacts to assessing contractor performance according to the UFGS.

1.3 Objective

This study compared volumetric and physical properties of HMA compacted by two available methods in UFGS 32-12-15.13. The specific objectives of this study included efforts to

- determine if using a specification requiring 75 SGC gyrations for HMA compaction produces a different product than using a specification requiring 75 blows of a manual Marshall hammer for HMA compaction
- determine if a contractor's percent payment is affected by the compaction option selected in the specification
- evaluate a laboratory performance test protocol for SGC-compacted specimens.

1.4 Scope

The scope of this study included collecting samples of asphalt mixtures during airfield paving projects and compacting specimens from the samples in a field laboratory at the construction site. The mixtures were sampled from transport trucks and then simultaneously compacted in the laboratory using both SGC and manual Marshall compaction. The density of the mixture compacted by each method was measured and compared. Results were analyzed to determine if the two compaction protocols produced different densities.

The mixtures compacted using the SGC were transported to the U.S. Army Engineer Research and Development Center's (ERDC's) Material Test Center (MTC) laboratory for additional physical property testing. The Asphalt Pavement Analyzer (APA) was used to assess rutting performance of the mixtures. These data were used to evaluate a draft test protocol for potential inclusion in construction specifications.

2 Review of UFGS 32-12-15.13

2.1 General discussion

UFGS 32-12-15.13, *Hot mix asphalt airfield paving*, provides protocol for designing and constructing dense graded asphalt mixtures for airfields. These protocols include laboratory procedures for designing asphalt mixtures as well as for performing quality control/quality assurance testing. The UFGS has several tailoring options that allow the specification to be written according to the designer's preference. For example, the general specification includes a tailoring option that lists both SI and English units of measurement. This tailoring option allows one to select the preferred unit. Once an option is selected, it continues throughout the document, while the alternative is deleted. In a similar manner, the designer can choose to use either the traditional Marshall compaction protocol or the newly-introduced SGC protocol. The option that is selected is used for designing the asphalt mixture and for testing the mixture in the laboratory during production and placement.

The mixture design portion of the specification is impacted by the selection of compaction method because it can influence the design binder content selected for the mixture. The selection of the design binder content will impact mixture costs as well as ease of placement and field compaction. The compaction effort specified for the Marshall and SGC compaction methods was selected to produce equivalent density for a given mixture. However, the two compaction methods have different mechanical principles and can produce different densities for some mixtures at the specified compaction efforts.

In addition to the mixture design, laboratory compaction is used to monitor mixture consistency during production by measuring the percent air voids of compacted specimens sampled from paving sublots. All volumetric properties, including percent air voids, are expected to remain similar to those produced during the mixture design. The specification provides limits on the variation from the mixture design that is acceptable. The compaction method can influence the inherent variability of the air voids of compacted specimens within a given sample.

2.2 Comparison of Marshall and Superpave options

The selection of compaction method for the UFGS specification influences both mixture design and quality control/quality assurance testing during production and placement. The following discussion provides details of the difference between the two methods.

2.2.1 Mixture design

During mixture design, the selected compaction method is used to produce specimens at varying asphalt contents. The asphalt content that results in specimens having 4.0 percent air voids is considered the design asphalt content. The aggregate and binder property requirements for the design method are identical. Aggregates must be sound, tough, durable particles with sufficient angularity and texture to provide good interlock. Binders must meet proper Performance Grade requirements. The only difference between the two methods is the compaction device.

In the Marshall method, 75 drops of a 10-lb compaction hammer are applied to each exposed face of a 4-in.-diam, 2.5-in.-high cylindrical specimen in a compaction mold. The SGC compacts 6-in.-diam specimens to 4.5-in. height by applying a constant vertical force and by rotating the compaction mold 75 times at an angle of 1.25 deg. The impact compaction of the Marshall apparatus and the kneading compaction of the SGC operate on different mechanical principles and do not produce the same rate of compaction for all mixtures. Hence, the two methods do not always produce the same density for a given mixture.

Many variations of the Marshall protocol have existed since its development in the 1940s. The 75-blow method currently specified has been used successfully for at least 50 years. A study by Rushing (2011) identified 70 gyrations as a reasonable compaction effort using the SGC to produce equivalent density to the 75-blow Marshall method. In the study, 54 mixtures were evaluated. The number of gyrations required to compact mixtures to the same density as the 75-blow Marshall method ranged from approximately 40 to 125. Only laboratory-designed and produced mixtures were included in the study.

In addition to density, specimens produced using the Marshall method are tested to determine stability and flow values. These values are determined by applying a vertical load at a constant strain rate (0.1 in. per minute) to the specimen placed horizontally in a semi-circular loading collar. The stability value is the peak load at failure; the flow value is the vertical displacement at the time of failure. Stability is an empirical measure of mixture strength; flow is an empirical measure of shear resistance. No physical testing of SGC-compacted specimens is required in the current UFGS. The highway paving industry has not yet adopted a common mechanical test for SGC-compacted specimens, even though the device is the most common compaction tool used or specified by highway departments.

2.2.2 Quality control/quality assurance testing

UFGS 32-12-15.13 specifies procedures for conducting quality control and quality assurance testing during HMA production and placement. One component of the testing is determining the air voids content of laboratory-compacted specimens produced from hot asphalt mix. The total payment to the contractor is reduced if the mean absolute deviation from the job mix formula (JMF) exceeds specified levels. The calculations are based upon the average air voids content from four random samples from a lot.

The procedure for determining the mean absolute deviation in laboratory air voids is identical for compaction using the Marshall hammer or the SGC. The procedure need only be changed to list the preferred compaction device. The variability of the compaction device may result in differences in the deviations from the JMF, but averaging results from four specimens should compensate for the differences.

3 Field-Collected Mixture Data

Samples of plant-produced mixtures were collected and tested to provide data for comparing properties of specimens compacted with the manual Marshall hammer and the SGC. These mixtures were from construction projects taking place in FY14 or from mixtures placed for accelerated pavement testing. A mobile laboratory (Figure 1) was assembled to allow for testing of hot mixtures produced at construction projects. The laboratory was enclosed in a trailer and powered by generators. A Pine Instruments AFGB compactor produced SGC specimens (Figure 2). A Marshall pedestal and manual hammer were used for producing Marshall specimens (Figure 3). A weigh station (Figure 4) consisting of a digital scale and water container for submerging specimens provided dry and wet weights for calculating volumetric properties. A pycnometer, vibratory plate, and vacuum pump were used in preparing theoretical maximum density samples (Figure 5). The succeeding sections of this chapter describe the mixtures and test results for each project.

Figure 1. Mobile asphalt laboratory.

Figure 2. Superpave gyratory compactor.

Figure 3. Manual Marshall compaction.

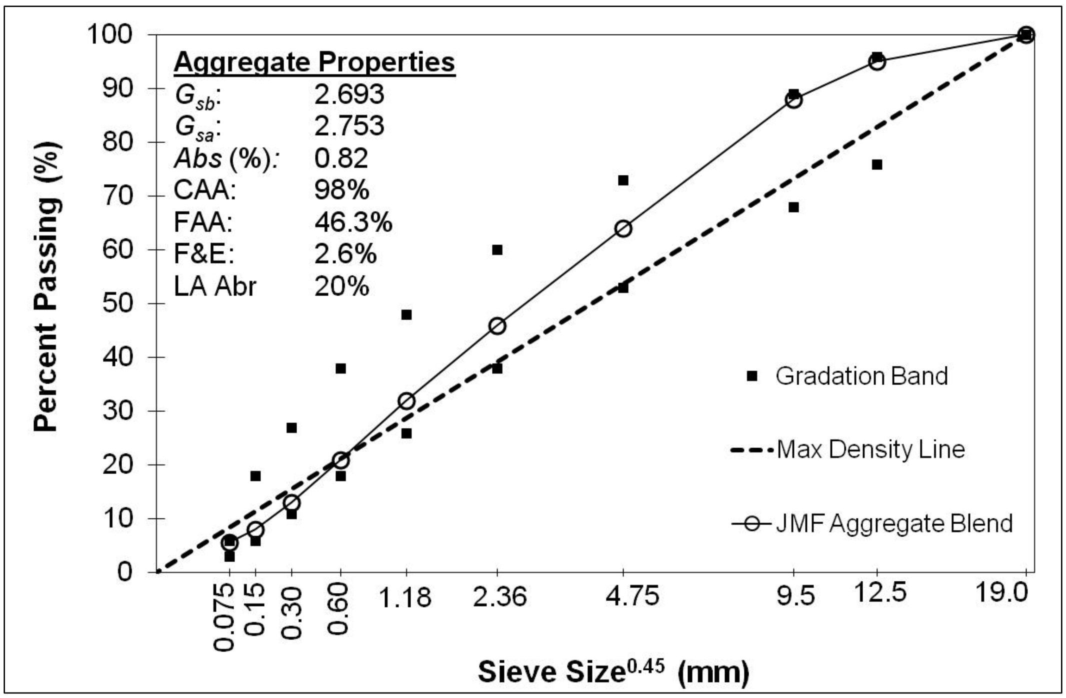
Figure 4. Asphalt specimen weigh station.

Figure 5. Apparatus for determining theoretical maximum density.

3.1 March Air Reserve Base, Moreno Valley, CA

HMA was placed on the outer edges and shoulders of Runway 14-32 from 17-19 April 2013. The mixture was designed according to UFGS 32-12-15.13 using the Marshall method. The maximum aggregate size was 0.75 in. (gradation 2), and the binder was a PG 70-10. The design binder content was 5.6 percent. Figure 6 shows the gradation of the mixture and pertinent properties that were supplied by the contractor.

Figure 6. Aggregate blend for March AFB mixture.



The ERDC mobile laboratory was stationed at the airfield during paving. The research team shoveled mixture samples from the hopper of the material transfer vehicle between loadings from haul trucks. Approximately 200 lb of material was sampled during periods throughout the day. A total of nine samples were taken. Each sample represented approximately one sublot of paving. The samples were placed in metal 5-gal buckets, sealed, and transported back to the mobile laboratory. At the laboratory, the mixture was scooped into metal containers using the appropriate mass to produce one compacted specimen. The containers were sealed and placed into an oven at the compaction temperature of 140°C for approximately 30 min prior to compacting with either the SGC (ASTM D 6925)(American Society for Testing and Materials International (ASTM) 2009) or the Marshall apparatus (ASTM D 6926)(ASTM 2010a). Shortly before compacting the mixtures, one container of appropriate mass was spread onto a large metal pan to separate the aggregate particles in preparation for determining the theoretical maximum density (TMD) according to ASTM D 2041 (ASTM 2011b). Each sample was divided to prepare six SGC specimens, six Marshall specimens, and two specimens for TMD tests.

Using multiple technicians, the mixtures were compacted simultaneously using both compaction devices. The compacted specimens were allowed to cool overnight before measuring the density and volumetric properties according to ASTM D 2726 (ASTM 2013). The compacted specimens were transported to the MTC laboratory to perform stability and flow tests on the Marshall specimens and to perform APA tests on the SGC specimens. APA tests were performed according to the procedure used by Rushing et al. (2012) to assess rutting potential for airfield HMA.

Portions of SGC specimens that were cut and removed to reduce specimen height to the target APA test height of 3 in. were tested using ASTM D 2172 (ASTM 2011a) to determine binder content by the extraction method. Two measurements were recorded and averaged. The effective specific gravity of the aggregate, G_{se}, was then determined using the measured binder content and the measured TMD. The calculation was performed twice for each sample using the two TMD values. Figure 7 shows the calculated G_{se} for each sample. The average G_{se} value for the aggregate was 2.75. This is the same G_{se} value reported in the contractor's mixture design.

To minimize testing variability associated with measuring TMD, values for each sample were calculated based upon the average G_{se} value of 2.75 and the measured binder content. The G_{se} is assumed to be constant. Using this value adjusts the TMD only for variations in binder content. The air voids content was determined using the calculated TMD value.

Figure 8 shows air voids content data for each sample from both SGC and Marshall compaction. The data shown in the figure represent the average and standard deviation of six compacted specimens. For this mixture, the design air voids content was 3.5 percent. The design was produced using the Marshall method. The first sample had a relatively high average air voids content. The results from binder extraction indicate the asphalt content was low for this sample. Low asphalt content hinders compaction and likely caused the air voids to be high. Sample 6 had a low air voids content. This sample had a binder content much higher than design, causing the air voids to be low. These samples do not necessarily represent the contractor's

Figure 7. Average G_{se} for March AFB specimens.

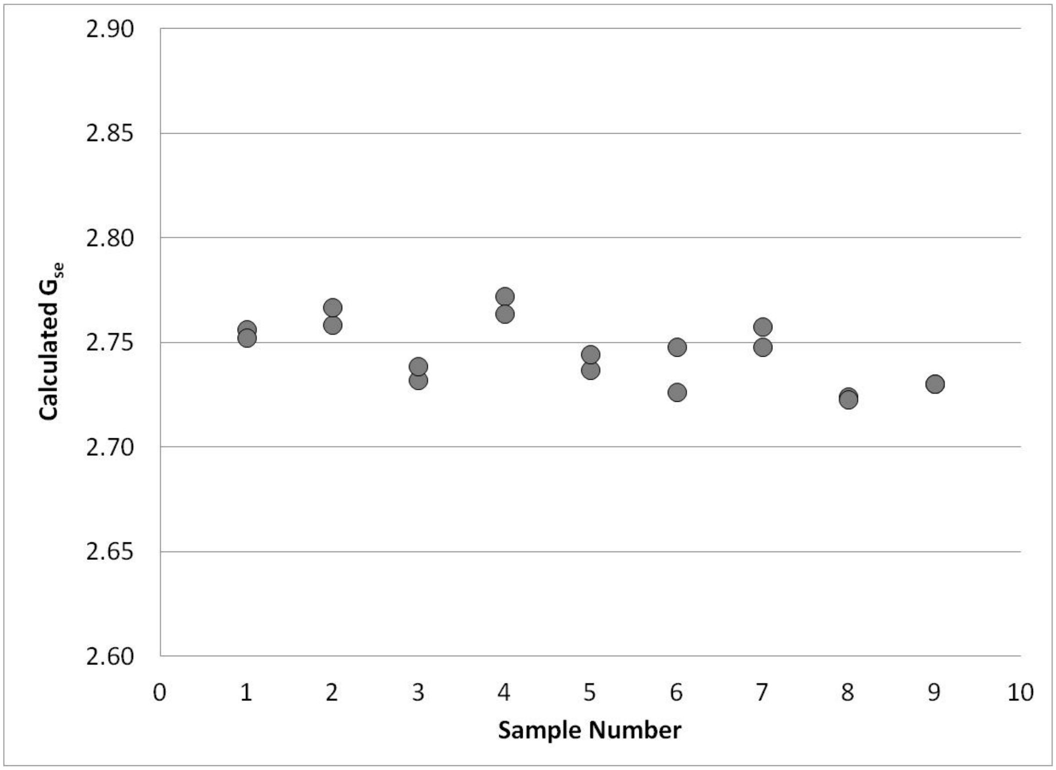
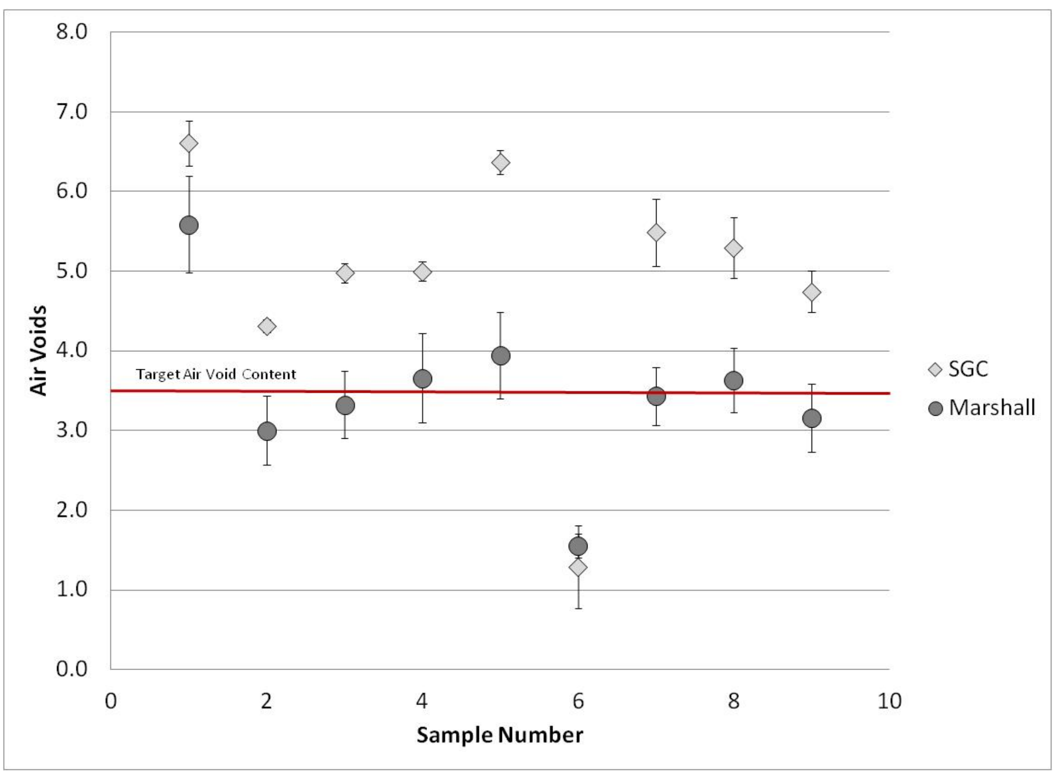


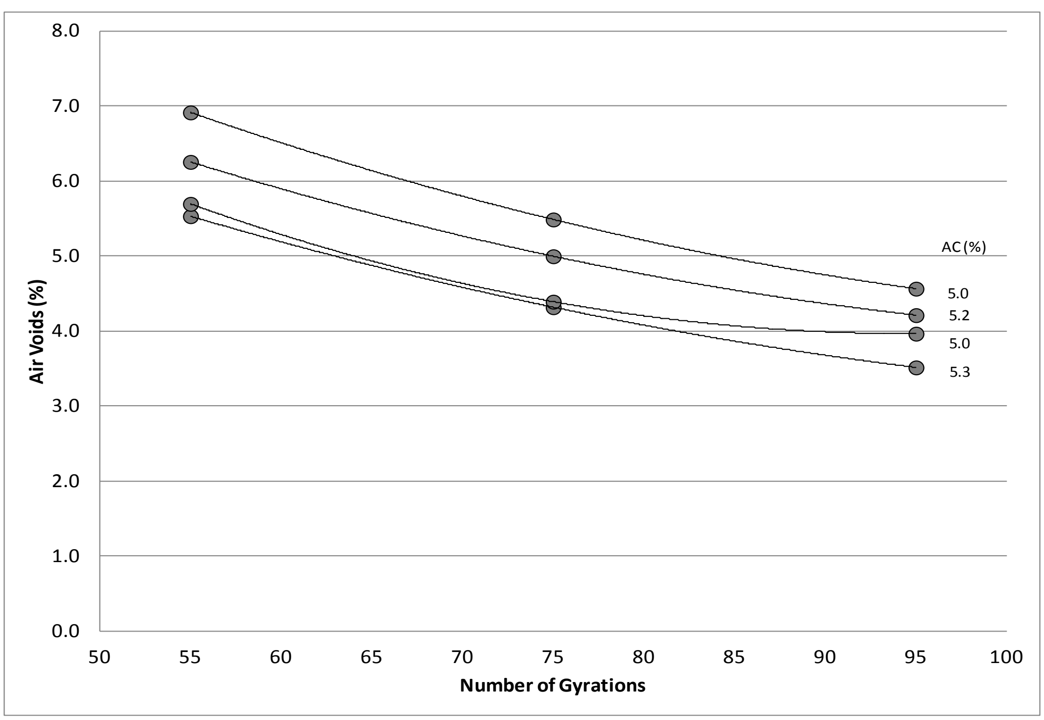
Figure 8. Average air voids content of March AFB specimens.



ability to produce a consistent product. Some variability is expected to result from the sampling procedures used to collect the mixture. For example, the sample was taken from a single location in the hopper. In most cases, the material was from the bottom and end of the truck bed since samples were taken after the truck dumped material into the MTV hopper. In the case of Sample 6, the mixture was very hot (160°C) in the truck. Having the mixture at such temperature could have caused the binder to drain towards the bottom of the truck, resulting in a sample of high binder content. When the mixture passed through the MTV, it was remixed and likely redistributed the binder more evenly. The pavement in the area where Sample 6 was taken showed no evidence of excessive binder. Additional properties of each sample are provided in Table A1 in Appendix A.

The air voids content for specimens compacted by the SGC was consistently higher than the air voids content measured on specimens compacted using the manual Marshall hammer. For this particular mixture, 75 gyrations in the SGC were not sufficient to achieve the design mixture density. On four of the samples taken from this project, the compaction effort was varied for the SGC to produce a compaction curve. For these samples, two specimens were compacted using 55 gyrations, two using 75 gyrations, and two using 95 gyrations. The average air voids content of specimens from these samples is shown in Figure 9 along with the asphalt content for the sample.

Figure 9. Compaction curves for March AFB specimens.



As expected, increasing the asphalt content tends to decrease the air voids content for a given compaction effort. All of the mixtures sampled had asphalt contents below the design of 5.6 percent. The highest asphalt content for the samples was 5.3 percent. For this sample, the compaction curve indicates 95 gyrations in the SGC would result in a compacted air voids content equal to the design of 3.5 percent. To achieve equal density to the Marshall device at 75 gyrations in the SGC, the asphalt content would need to be increased by approximately 0.3 percent.

All field-compacted specimens were transported to the ERDC laboratory for mechanical testing. Marshall specimens were tested to determine stability and flow values according to ASTM D 6927 (ASTM 2006). Figure 10 shows these values on their corresponding axis. The UFGS specifies a minimum stability value of 2,150 lb and a flow value between 8 and 16. The average values for all samples (except Sample 6) met these requirements. The average stability was greater than 3,000 lb, and the flow values were typically between 9 and 14. For Sample 6, the stability and flow values averaged 2,088 lb and 29, respectively. Low stability and high flow values are typical when a mixture has excessive binder. Table 1 provides volumetric properties and stability and flow results for Marshall specimens.

Figure 10. Marshall stability and flow for March AFB specimens.

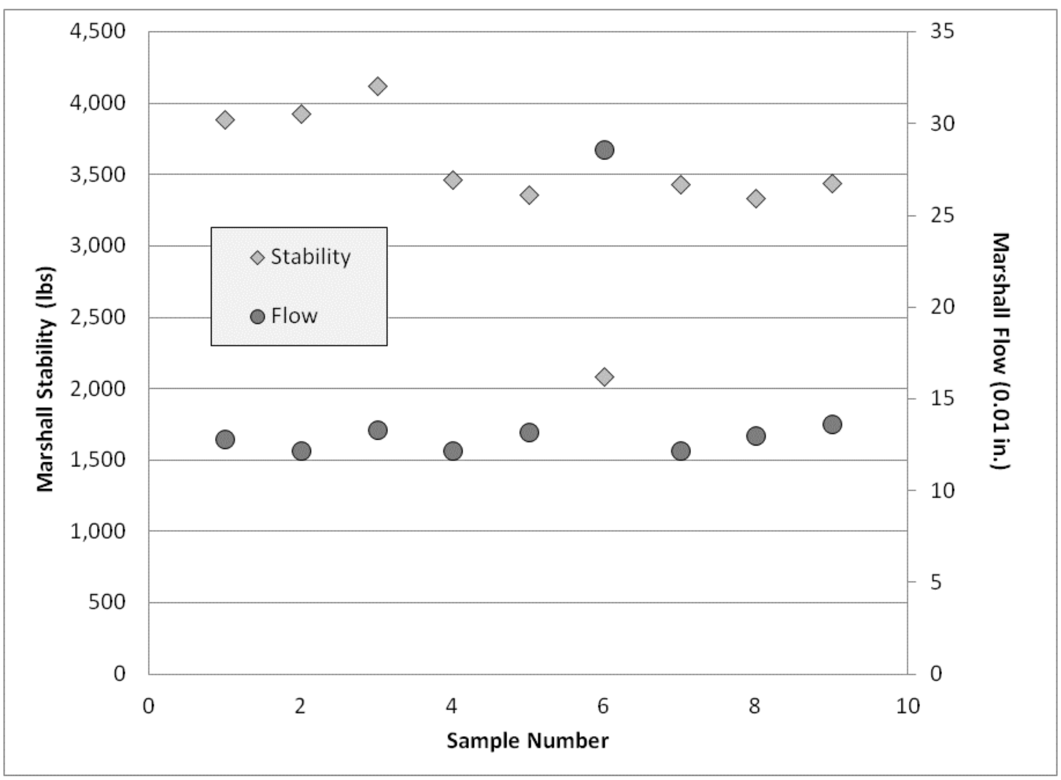


Table 1. March AFB data for Marshall specimens.

Sample #	Specimen #	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	Stability	Flow
1	M001	4.74	2.384	2.549	6.5	15.9	59.5	3,439	10
	M002	4.74	2.407	2.549	5.5	15.1	72.9	3,894	12
	M003	4.74	2.398	2.549	5.9	15.4	71.1	3,657	11
	M004	4.74	2.402	2.549	5.8	15.3	71.8	4,132	16
	M005	4.74	2.427	2.549	4.8	14.4	77.1	4,102	15
	M006	4.74	2.419	2.549	5.1	14.7	75.3	4,102	13
2	M007	5.27	2.444	2.528	3.3	14.3	76.8	3,558	11
	M008	5.27	2.453	2.528	3.0	14.0	89.3	3,617	11
	M009	5.27	2.471	2.528	2.2	13.3	94.2	4,607	14
	M010	5.27	2.439	2.528	3.5	14.5	85.8	3,666	12
	M011	5.27	2.452	2.528	3.0	14.0	89.0	4,231	13
	M012	5.27	2.453	2.528	3.0	14.0	89.1	3,884	12
3	M013	5.18	2.437	2.531	3.7	14.5	74.3	3,904	13
	M014	5.18	2.463	2.531	2.7	13.5	90.9	4,102	13
	M015	5.18	2.447	2.531	3.3	14.1	86.8	3,577	12
	M016	5.18	2.439	2.531	3.6	14.4	84.7	4,379	15
	M017	5.18	2.456	2.531	3.0	13.8	89.0	4,181	14
	M018	5.18	2.439	2.531	3.6	14.4	84.8	4,577	13
4	M019	5.18	2.428	2.531	4.1	14.8	72.4	3,063	12
	M020	5.18	2.450	2.531	3.2	14.0	87.3	3,468	13
	M021	5.18	2.423	2.531	4.2	14.9	81.1	3,231	12
	M022	5.18	2.450	2.531	3.2	14.0	87.6	3,835	13
	M023	5.18	2.453	2.531	3.1	13.9	88.2	4,062	13
	M024	5.18	2.425	2.531	4.2	14.9	81.6	3,142	10
5	M025	4.98	2.438	2.539	4.0	14.2	72.1	3,092	12
	M026	4.98	2.445	2.539	3.7	14.0	84.1	3,142	12
	M027	4.98	2.423	2.539	4.6	14.8	78.9	3,498	13
	M028	4.98	2.458	2.539	3.2	13.5	87.3	3,845	14
	M029	4.98	2.430	2.539	4.3	14.5	80.3	3,211	15
	M030	specimen not available							
6	M031	7.18	2.416	2.456	1.6	17.0	90.3	1,954	26
	M032	specimen not available							
	M033	7.18	2.419	2.456	1.5	16.9	99.2	2,092	29
	M034	7.18	2.421	2.456	1.4	16.8	99.6	2,112	28
	M035	7.18	2.413	2.456	1.8	17.1	97.6	2,082	31
	M036	7.18	2.421	2.456	1.4	16.8	99.7	2,201	29

Sample #	Specimen #	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	Stability	Flow
7	M037	4.99	2.439	2.538	3.9	14.2	72.8	3,538	11
	M038	4.99	2.445	2.538	3.6	14.0	84.2	3,082	10
	M039	4.99	2.457	2.538	3.2	13.6	87.2	3,716	15
	M040	4.99	2.463	2.538	2.9	13.4	88.7	3,389	13
	M041	4.99	2.454	2.538	3.3	13.7	86.4	3,587	11
	M042	4.99	2.443	2.538	3.7	14.1	83.5	3,300	13
8	M043	4.90	2.446	2.542	3.8	13.9	72.8	3,340	14
	M044	4.90	2.436	2.542	4.2	14.3	80.8	2,736	13
	M045	4.90	2.460	2.542	3.2	13.4	86.8	3,261	11
	M046	4.90	2.456	2.542	3.4	13.5	85.8	3,716	15
	M047	4.90	2.441	2.542	4.0	14.1	82.1	3,191	12
	M048	4.90	2.460	2.542	3.2	13.4	86.7	3,765	13
9	M049	5.02	2.447	2.537	3.5	14.0	74.6	2,904	13
	M050	5.02	2.445	2.537	3.6	14.0	84.4	2,904	14
	M051	5.02	2.466	2.537	2.8	13.3	90.0	3,657	14
	M052	5.02	2.467	2.537	2.8	13.3	90.2	3,765	15
	M053	5.02	2.449	2.537	3.5	13.9	85.3	3,350	13
	M054	5.02	2.467	2.537	2.8	13.3	90.1	4,092	13
	Average	**5.24**	**2.440**	**2.529**	**3.5**	**14.4**	**83.9**	**3,479**	**14**

Specimens compacted in the SGC were tested in the APA. Because the height of the specimens was 115 mm, they were cut using a wet block saw to 75 mm, the target test height. The uncut end was placed upward in the APA to apply the load on the undisturbed face. The test temperature was set to 70°C, the high performance grade (PG) temperature for the binder. The applied load was 250 lb, and the hose pressure was 250 psi. Testing was performed until 8,000 cycles were applied or the rut depth exceeded 12 mm. The six specimens from each sample were tested together. The accumulated rut depth for all specimens is shown in Figure 11. These data do not include the specimens from Sample 6 that contained excessive binder.

Individual specimen numbers are not noted in Figure 11 because of the large number of data presented. However, Table 2 provides the rut depth after 4,000 APA cycles. The data show significant variability among the results. On average, the rut depth was 10.6 mm after 4,000 APA cycles. By comparison to mixtures tested by Rushing et al. (2012), this mixture is of marginal quality in terms of rutting.

Figure 11. APA data for March AFB specimens.

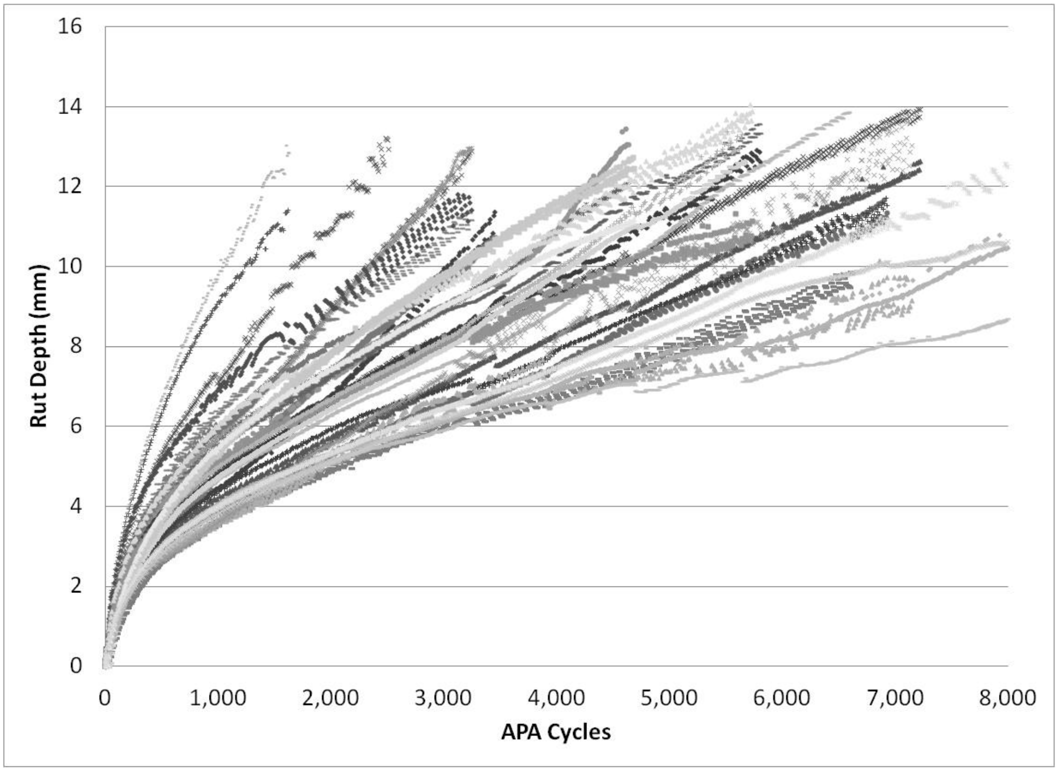


Table 2. March AFB data for SGC specimens.

Sample #	Specimen #	Number of Gyrations	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	APA Rut Depth After 4,000 Cycles[1]
1	G001	75	4.74	2.368	2.549	7.1	16.5	56.9	13.0
	G002	75	4.74	2.381	2.549	6.6	16.0	58.9	12.5
	G003	75	4.74	2.389	2.549	6.3	15.8	60.2	8.3
	G004	75	4.74	2.383	2.549	6.5	16.0	59.3	9.3
	G005	75	4.74	2.383	2.549	6.5	16.0	59.3	10.9
	G006	75	4.74	2.378	2.549	6.7	16.1	58.5	10.9
2	G007	55	5.27	2.394	2.528	5.3	16.1	66.9	12.5
	G008	55	5.27	2.389	2.528	5.5	16.2	66.1	13.5
	G009	75	5.27	2.420	2.528	4.3	15.1	71.8	10.1
	G010	75	5.27	2.417	2.528	4.4	15.2	71.3	9.5
	G011	95	5.27	2.430	2.528	3.9	14.8	73.9	11.3
	G012	95	5.27	2.448	2.528	3.2	14.2	77.6	11.1
3	G013	75	5.18	2.406	2.531	4.9	15.6	68.2	14.0
	G014	75	5.18	2.406	2.531	4.9	15.6	68.2	14.0
	G015	75	5.18	2.409	2.531	4.8	15.4	68.8	7.5
	G016	75	5.18	2.405	2.531	5.0	15.6	68.1	7.9
	G017	75	5.18	2.400	2.531	5.2	15.8	67.1	6.7
	G018	75	5.18	2.404	2.531	5.0	15.6	67.9	8.9

Sample #	Specimen #	Number of Gyrations	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	APA Rut Depth After 4,000 Cycles[1]
4	G019	55	5.18	2.371	2.531	6.3	16.8	62.3	19.0
	G020	55	5.18	2.385	2.531	5.8	16.3	64.6	17.0
	G021	75	5.18	2.407	2.531	4.9	15.5	68.4	10.5
	G022	75	5.18	2.402	2.531	5.1	15.7	67.6	16.0
	G023	95	5.18	2.425	2.531	4.2	14.9	71.8	11.9
	G024	95	5.18	2.424	2.531	4.2	14.9	71.6	12.8
5	G025	75	4.98	2.373	2.539	6.5	16.5	60.4	16.0
	G026	75	4.98	2.377	2.539	6.4	16.4	61.0	18.0
	G027	75	4.98	2.379	2.539	6.3	16.3	61.3	12.5
	G028	75	4.98	2.375	2.539	6.5	16.5	60.8	12.5
	G029	75	4.98	2.376	2.539	6.4	16.4	61.0	9.2
	G030	75	4.98	2.384	2.539	6.1	16.1	62.2	10.7
6	G031	75	7.18	2.434	2.456	0.9	16.4	94.6	Not tested[1]
	G032	75	7.18	2.424	2.456	1.3	16.7	92.1	Not tested[1]
	G033	75	7.18	2.428	2.456	1.2	16.6	93.0	Not tested[1]
	G034	75	7.18	2.434	2.456	0.9	16.4	94.5	Not tested[1]
	G035		specimen not available						
	G036		specimen not available						
7	G037	55	4.99	2.363	2.538	6.9	16.9	59.2	7.7
	G038	55	4.99	2.362	2.538	6.9	16.9	59.1	9.9
	G039	75	4.99	2.391	2.538	5.8	15.9	63.6	6.9
	G040	75	4.99	2.406	2.538	5.2	15.4	66.3	8.2
	G041	95	4.99	2.424	2.538	4.5	14.8	69.6	4.6
	G042	95	4.99	2.420	2.538	4.6	14.9	68.8	4.1
8	G043	75	4.90	2.405	2.542	5.4	15.3	64.8	10.0
	G044	75	4.90	2.389	2.542	6.0	15.9	62.2	9.9
	G045	75	4.90	2.411	2.542	5.2	15.1	65.9	6.6
	G046	75	4.90	2.415	2.542	5.0	15.0	66.6	7.0
	G047	75	4.90	2.414	2.542	5.0	15.0	66.5	11.6
	G048	75	4.90	2.411	2.542	5.1	15.1	66.0	10.4
9	G049	75	5.02	2.412	2.537	4.9	15.2	67.6	7.2
	G050	75	5.02	2.421	2.537	4.6	14.9	69.3	7.5
	G051	55	5.02	2.391	2.537	5.8	15.9	63.9	6.9
	G052	55	5.02	2.394	2.537	5.6	15.8	64.4	7.1
	G053	95	5.02	2.437	2.537	3.9	14.3	72.5	8.9
	G054	95	5.02	2.436	2.537	4.0	14.4	72.2	9.1
	Average[2]		**4.99**	**2.397**	**2.538**	**5.6**	**15.7**	**64.6**	**10.6**

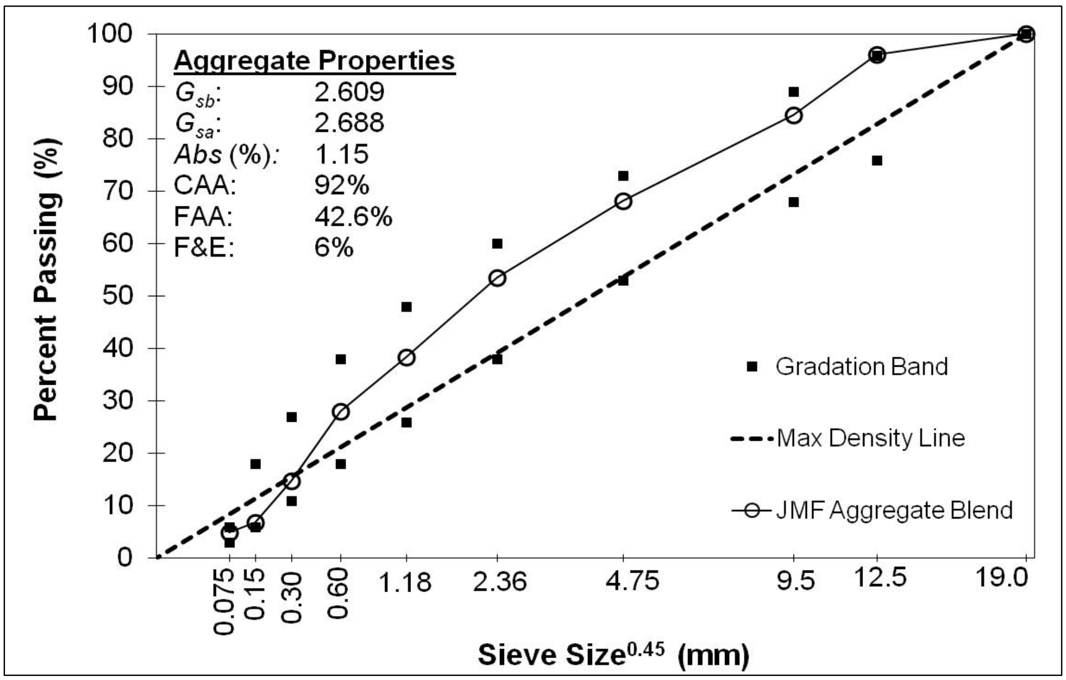
[1] Specimens G031-G034 had excessive binder and were not tested in APA.

[2] Excludes specimens compacted to 55 or 95 gyrations.

3.2 U.S. Army Engineer Research and Development Center, Vicksburg, MS

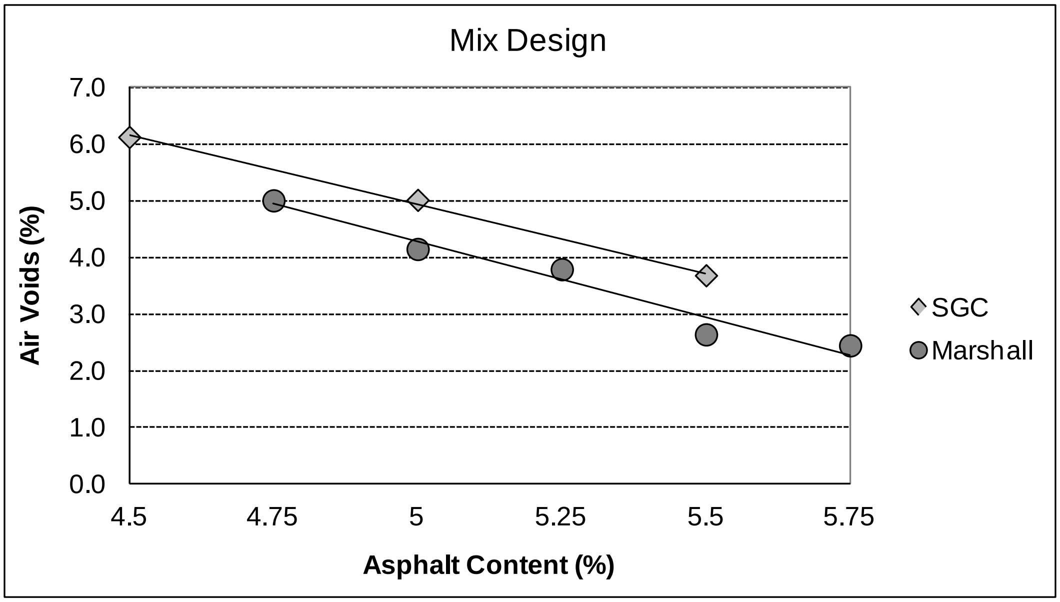
An asphalt concrete test section was constructed during 2012 at the Hangar 4 accelerated pavement test facility at ERDC. The HMA mix design was performed by ERDC personnel. The aggregate blend consisted of 25 percent crushed gravel, 60 percent limestone, and 15 percent natural sand. The aggregate sources and blend were selected based on materials available for plant production. The aggregate gradation from the mix design is provided in Figure 12.

Figure 12. Aggregate blend for ERDC mixture.



The mixture used in this study was designed using 75 gyrations in the SGC in accordance with UFGS 32-12-15.13 requirements. Target volumetric properties were air voids (V_a) of 4 percent and minimum voids in mineral aggregate (VMA) of 14.0 percent. The design asphalt content was 5.3 percent. When the mixture was designed using 75 blows of the manual Marshall hammer, the design asphalt content was 5.1 percent. The percent air voids for specimens produced using varying asphalt contents during the mix design is shown in Figure 13. Compaction data from this mixture indicate that using the SGC to produce the design results in an increase in design asphalt content of approximately 0.25 percent. APA tests from this mixture resulted in an average rut depth of 10.5 mm after 4,000 cycles (Doyle et al. 2013).

Figure 13. SGC and Marshall mix design results for ERDC mixture.



3.3 Highway 41, Monroe County, MS

HMA was placed on Highway 41 in Monroe County, MS from 25-27 June 2013. The mixture was designed according to Mississippi Department of Transportation specifications for a 9.5-nominal maximum aggregate size, medium traffic mixture. The design number of gyrations was 65, and the design binder content was 6.2 percent to achieve 4.0 percent air voids. The binder was an unmodified PG 67-22. The mixture contained 15 percent reclaimed asphalt concrete (RAP) with a binder content of 5.5 percent. The percent binder added to the mixture was 5.38 percent to achieve the desired total binder content. Figure 14 shows the gradation of the mixture and pertinent properties that were supplied by the contractor.

Mixture from each sample was tested using ASTM D 6307 (ASTM 2010b) to determine binder content by the ignition oven method. Two measurements were recorded and averaged. The effective specific gravity of the aggregate, G_{se}, was then determined using the measured binder content and the measured TMD. The calculation was performed twice for each sample using the two TMD values. Figure 15 shows the calculated G_{se} for each sample. The average G_{se} value for the aggregate was 2.562. This value is slightly less than the G_{se} value of 2.589 reported in the contractor's mixture design. The aggregate used for asphalt production is known to have high absorption and a variable G_{se}.

Figure 14. Aggregate blend for Monroe County mixture.

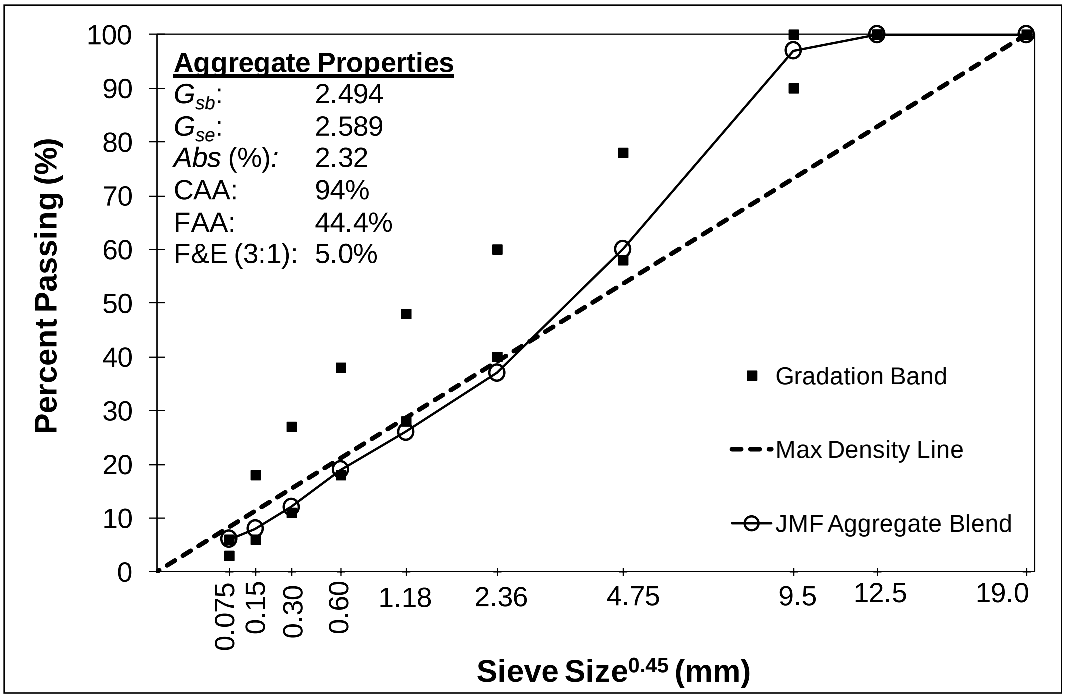


Figure 15. Average G_{se} for Monroe County specimens.

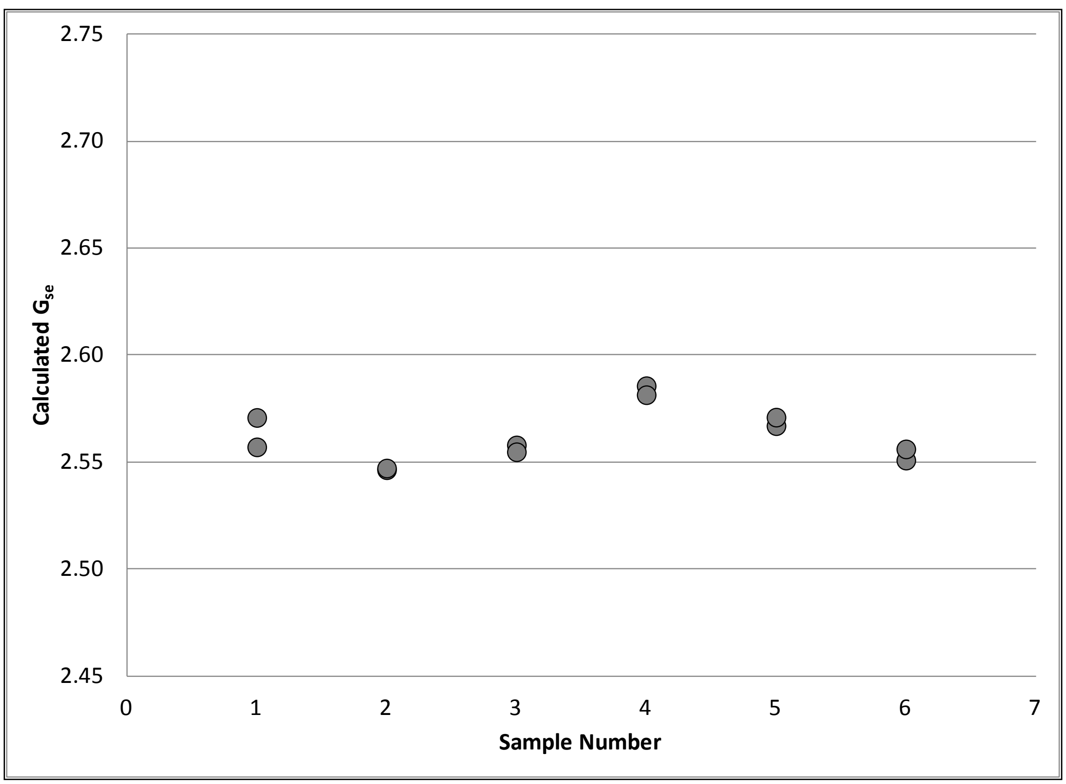


Figure 16 shows that the air voids content for specimens compacted by the SGC was similar to the air voids content measured on specimens compacted using the manual Marshall hammer. On three samples taken from this project, the compaction effort was varied for the SGC to produce a compaction curve. For these samples, two specimens were compacted using 55 gyrations, two using 75 gyrations, and two using 95 gyrations. The average air voids content of specimens from these samples is shown in Figure 17 along with the asphalt content for the sample. Increasing the asphalt content decreased the air voids content for a given compaction effort. The air voids content at the design number of gyrations (65) was approximately 4.0 percent, the target value. For this mixture, using the SGC or Marshall method to design the mixture should result in the same design asphalt content.

Figure 18 provides stability and flow data for Marshall specimens. The average stability value was 3,428 lb, and the average flow was 14. These values indicate an acceptable asphalt mixture. Volumetric properties and stability and flow values for each specimen are given in Table 3.

Figure 16. Average air voids content of Monroe County specimens.

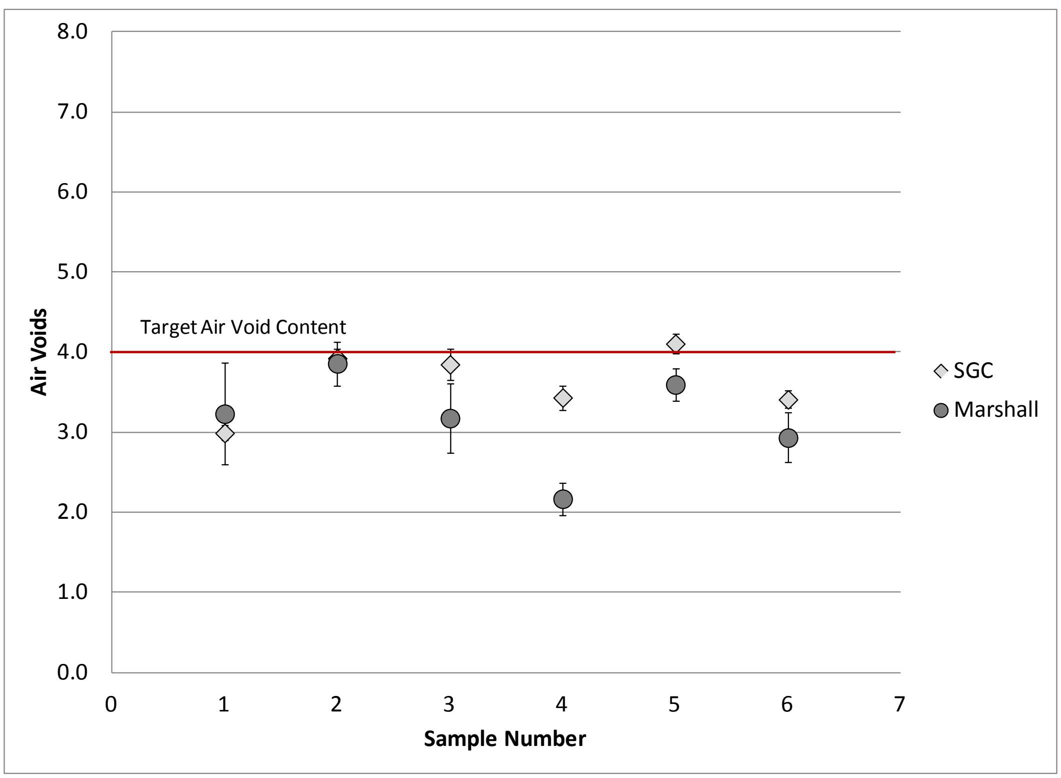


Figure 17. Compaction curves for Monroe County specimens.

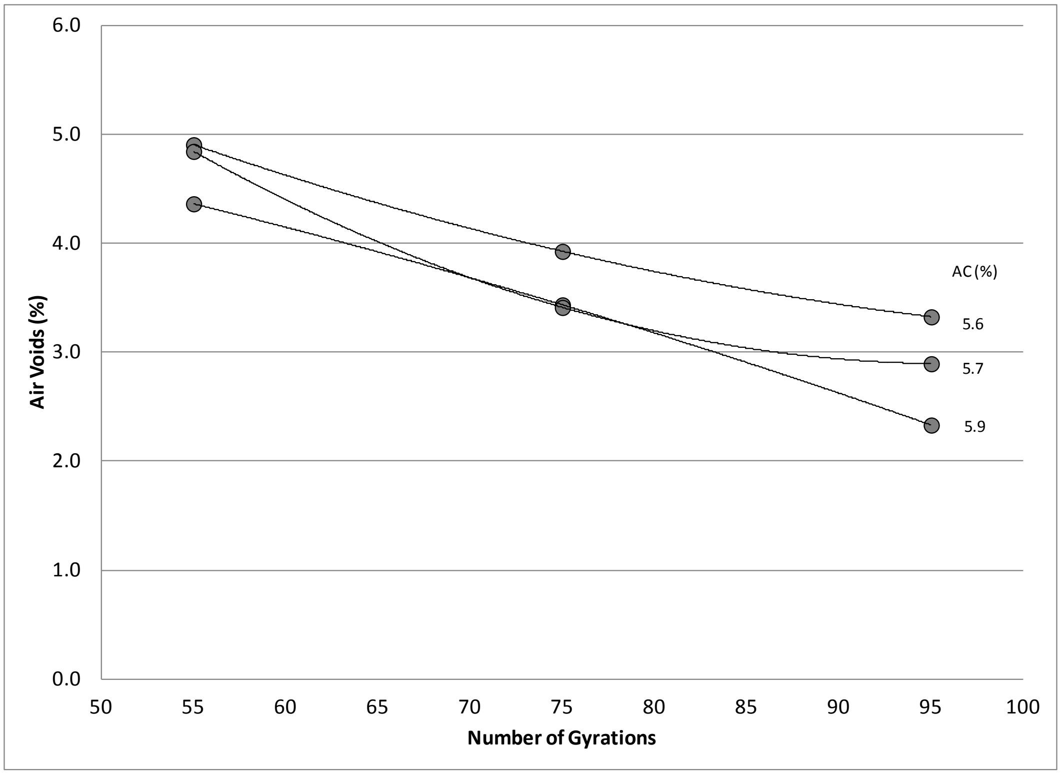


Figure 18. Marshall stability and flow for Monroe County specimens.

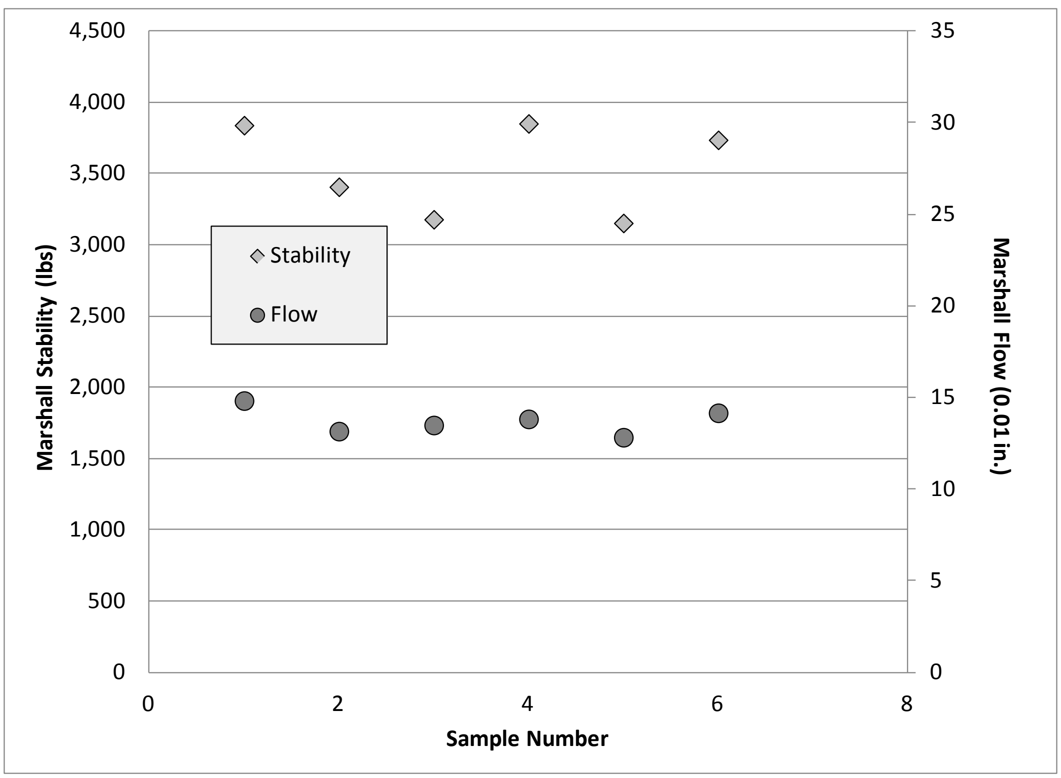


Table 3. Monroe County data for Marshall specimens.

Sample #	Specimen #	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	Stability	Flow
1	M101	5.75	2.272	2.372	4.2	14.2	70.3	3,455	16
	M102	5.75	2.283	2.372	3.8	13.8	72.6	3,465	14
	M103	5.75	2.298	2.372	3.1	13.2	76.3	3,455	13
	M104	5.75	2.309	2.372	2.7	12.8	79.0	4,072	15
	M105	5.75	2.303	2.372	2.9	13.0	77.6	4,031	15
	M106	5.75	2.310	2.372	2.6	12.8	79.3	4,556	16
2	M107	5.60	2.281	2.377	4.1	13.7	70.4	3,126	15
	M108	5.60	2.284	2.377	3.9	13.6	71.2	2,971	14
	M109	5.60	2.276	2.377	4.3	13.9	69.3	3,476	12
	M110	5.60	2.291	2.377	3.6	13.4	72.7	3,579	15
	M111	5.60	2.290	2.377	3.7	13.4	72.6	3,620	12
	M112	5.60	2.292	2.377	3.6	13.3	72.9	3,671	11
3	M113	5.73	2.291	2.373	3.5	13.5	74.3	3,033	12
	M114	5.73	2.282	2.373	3.8	13.8	72.2	3,064	15
	M115	5.73	2.299	2.373	3.1	13.2	76.3	3,311	12
	M116	5.73	2.297	2.373	3.2	13.2	75.7	2,961	12
	M117	5.73	2.306	2.373	2.8	12.9	78.1	3,280	14
	M118	5.73	2.311	2.373	2.6	12.7	79.4	3,424	16
4	M119	5.87	2.315	2.369	2.3	12.7	82.2	3,815	17
	M120	5.87	2.309	2.369	2.5	12.9	80.6	3,373	15
	M121	5.87	2.321	2.369	2.0	12.5	83.9	3,825	11
	M122	5.87	2.316	2.369	2.2	12.7	82.4	3,990	12
	M123	5.87	2.323	2.369	1.9	12.4	84.5	3,949	13
	M124	5.87	2.318	2.369	2.1	12.6	83.1	4,155	15
5	M125	5.87	2.288	2.369	3.4	13.7	75.2	3,023	13
	M126	5.87	2.282	2.369	3.7	13.9	73.7	3,280	17
	M127	5.87	2.283	2.369	3.6	13.9	74.1	3,239	12
	M128	5.87	2.275	2.369	4.0	14.2	72.1	3,033	12
	M129	5.87	2.288	2.369	3.4	13.7	75.1	3,126	11
	M130	5.87	2.284	2.369	3.5	13.8	74.3	3,218	12
6	M131	5.65	2.305	2.376	3.0	12.9	76.8	3,434	16
	M132	5.65	2.300	2.376	3.2	13.0	75.6	3,527	15
	M133	5.65	2.307	2.376	2.9	12.8	77.5	3,733	13
	M134	5.65	2.296	2.376	3.3	13.2	74.6	3,558	12
	M135	5.65	2.311	2.376	2.7	12.6	78.5	4,052	14
	M136	5.65	2.316	2.376	2.5	12.4	79.9	4,114	15
	Average	5.75	2.298	2.373	3.2	13.2	76.2	3,528	14

Specimens compacted in the SGC were tested in the APA. The test temperature was set to 64°C, the high PG grade temperature for the binder. The applied load was 250 lb, and the hose pressure was 250 psi. Testing was performed until 8,000 cycles were applied or the rut depth exceeded 12 mm. The six specimens from each sample were tested together. The accumulated rut depth for all specimens is shown in Figure 19.

Individual specimen numbers are not noted in Figure 19 because of the large number of data presented. However, Table 4 provides the rut depth after 4,000 APA cycles for each specimen. The average rut depth after 4,000 APA cycles was 6.2 mm for this mixture. By comparison to mixtures tested by Rushing et al. (2012), this mixture is of good quality in terms of rutting.

Figure 19. APA data for Monroe County specimens.

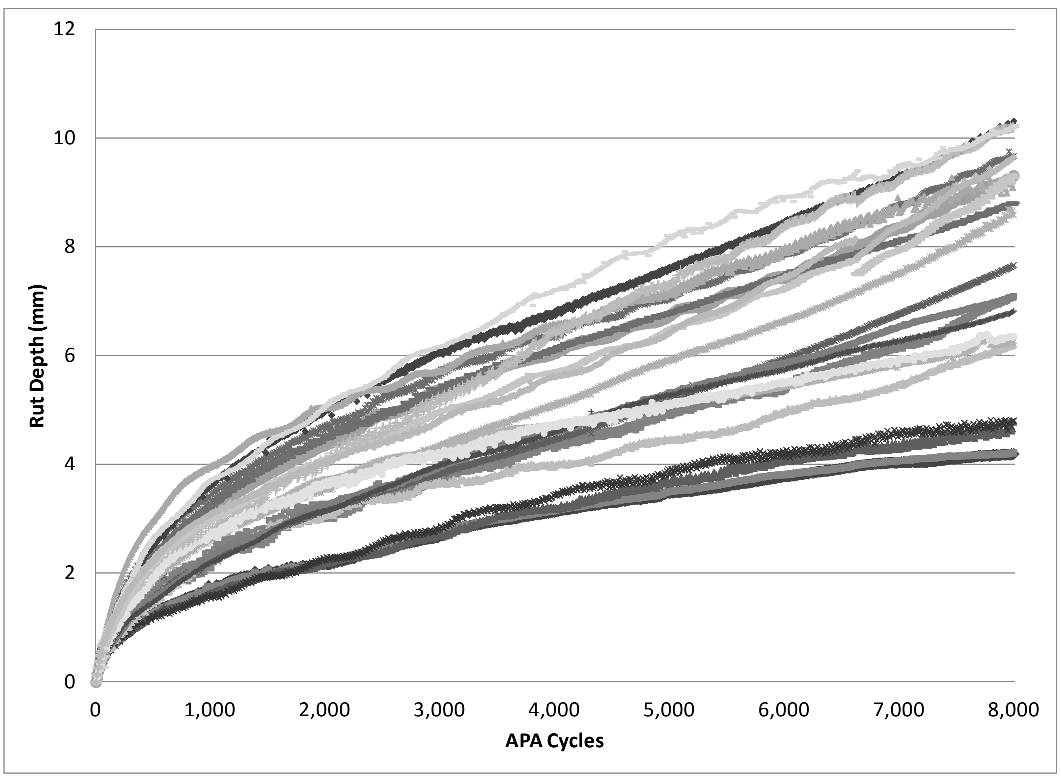


Table 4. Monroe County data for SGC specimens.

Sample #	Specimen #	Number of Gyrations	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	APA Rut Depth After 4,000 Cycles
1	G101	75	5.75	2.304	2.372	2.9	13.0	77.7	3.1[1]
	G102	75	5.75	2.302	2.372	3.0	13.0	77.4	3.2[1]
	G103	75	5.75	2.303	2.372	2.9	13.0	77.6	3.2[1]
	G104	75	5.75	2.301	2.372	3.0	13.1	77.1	3.5[1]
	G105	75	5.75	2.297	2.372	3.2	13.2	76.1	6.4
	G106	75	5.75	2.301	2.372	3.0	13.1	76.9	6.0
2	G107	55	5.60	2.259	2.377	5.0	14.6	65.7	6.9
	G108	55	5.60	2.263	2.377	4.8	14.4	66.6	8.0
	G109	75	5.60	2.286	2.377	3.8	13.5	71.6	6.1
	G110	75	5.60	2.282	2.377	4.0	13.7	70.7	6.7
	G111	95	5.60	2.297	2.377	3.4	13.1	74.2	4.4
	G112	95	5.60	2.300	2.377	3.3	13.0	74.9	4.0
3	G113	75	5.73	2.275	2.373	4.1	14.1	70.6	4.5
	G114	75	5.73	2.284	2.373	3.7	13.7	72.7	5.1
	G115	75	5.73	2.278	2.373	4.0	13.9	71.3	4.7
	G116	75	5.73	2.281	2.373	3.9	13.8	72.0	4.6
	G117	75	5.73	2.288	2.373	3.6	13.6	73.5	Not tested
	G118	75	5.73	2.284	2.373	3.7	13.7	72.8	Not tested
4	G119	75	5.87	2.263	2.369	4.5	14.7	69.5	7.8
	G120	75	5.87	2.268	2.369	4.3	14.5	70.6	7.8
	G121	75	5.87	2.287	2.369	3.4	13.7	75.0	6.6
	G122	Specimen not available							
	G123	95	5.87	2.317	2.369	2.2	12.6	82.7	4.7
	G124	95	5.87	2.310	2.369	2.5	12.9	80.7	4.7
5	G125	75	5.87	2.272	2.369	4.1	14.3	71.4	6.4
	G126	75	5.87	2.277	2.369	3.9	14.1	72.6	7.2
	G127	75	5.87	2.271	2.369	4.1	14.4	71.2	5.7
	G128	75	5.87	2.269	2.369	4.2	14.4	70.9	5.6
	G129	75	5.87	2.269	2.369	4.2	14.4	71.0	6.7
	G130	75	5.87	2.270	2.369	4.2	14.4	71.0	6.7
6	G131	55	5.65	2.255	2.376	5.1	14.7	65.6	Equipment failure
	G132	55	5.65	2.266	2.376	4.6	14.3	67.8	Equipment failure
	G133	75	5.65	2.293	2.376	3.5	13.3	73.8	Equipment failure
	G134	75	5.65	2.296	2.376	3.3	13.2	74.7	Equipment failure
	G135	95	5.65	2.307	2.376	2.9	12.8	77.4	Equipment failure
	G136	95	5.65	2.307	2.376	2.9	12.8	77.3	Equipment failure
	Average[1]		5.76	2.286	2.372	3.6	13.7	73.4	6.2

[1] APA tests performed at 100-psi hose pressure/100-lb load

[2]Excludes specimens compacted to 55 or 95 gyrations

3.4 Columbus Air Force Base, Columbus, MS

HMA was placed on the wings and shoulders of Runway 13-31 in July and August 2013. The mixture was designed according to UFGS 32-12-15.13 using the SGC method. The HMA consisted of two lifts. The first lift is described as the base mixture; the second lift is described as the surface mixture.

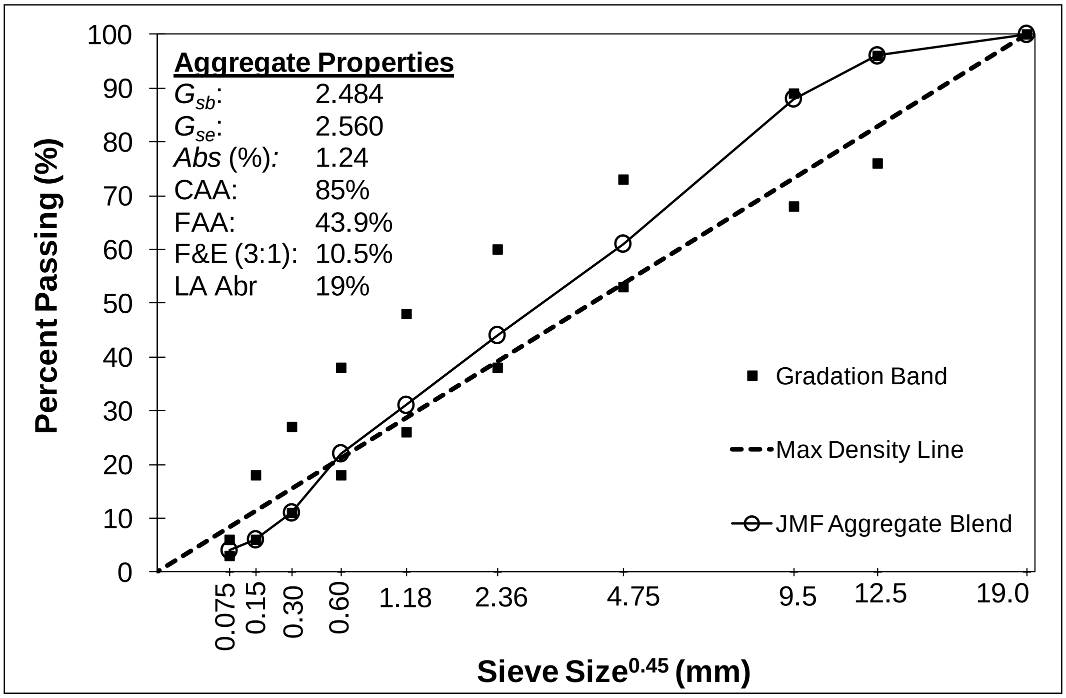
The ERDC mobile laboratory was stationed at the asphalt plant during paving. The research team shoveled mixture samples from the bed of haul trucks from an elevated platform at the plant. Approximately 200 lb of material was sampled during periods throughout the day. A total of nine samples were taken. Six samples were taken from the surface mixture, and three samples were taken from the base mixture. Each sample represented approximately one sublot of paving. The samples were placed in metal 5-gal buckets, sealed, and transported back to the mobile laboratory. At the laboratory, the mixture was scooped into metal containers using the appropriate mass to produce one compacted specimen. The containers were sealed and placed into an oven at the compaction temperature of 154°C for approximately 30 min prior to compacting with either the SGC or the Marshall apparatus. Shortly before compacting the mixtures, one container of appropriate mass was spread onto a large metal pan to separate the aggregate particles in preparation for determining TMD. Each sample was divided to prepare six SGC specimens, six Marshall specimens, and two TMD tests.

Using multiple technicians, the mixtures were compacted simultaneously using both compaction devices. The compacted specimens were allowed to cool overnight before measuring the density and volumetric properties. The compacted specimens were transported to the MTC laboratory to perform stability and flow tests on the Marshall specimens and to perform APA tests on the SGC specimens.

3.4.1 Surface mixture

The surface mixture had a maximum aggregate size of 0.75 in. (gradation 2), and the binder was a polymer-modified PG 76-22. The design binder content was 6.0 percent to achieve a target air voids content of 4.0 percent using 75 gyrations of the SGC. The percent natural sand was 15 percent, the maximum allowed by the specification. The fine aggregate angularity was 43.9 percent, slightly below the minimum specified value of 45 percent. Figure 20 shows the gradation of the mixture and pertinent properties that were supplied by the contractor.

Figure 20. Aggregate blend for Columbus AFB surface mixture.



Mixture from each sample was tested using ASTM D 6307 (ASTM 2010b) to determine binder content by the ignition oven method. Two measurements were recorded and averaged. The effective specific gravity of the aggregate, G_{se}, was then determined using the measured binder content and the measured TMD. The calculation was performed twice for each sample using the two TMD values. Figure 21 shows the calculated G_{se} for each sample. The average G_{se} value for the surface aggregates was 2.574. This value is near the G_{se} values of 2.560 reported in the contractor's mixture design for the surface aggregates.

Figure 22 shows air voids content data for each sample from both SGC and Marshall compaction for the surface mix. The data shown in the figure represent the average and standard deviation of six compacted specimens. For this mixture, the design air voids content was 4.0 percent. The design was produced using the SGC method. The first three samples had an air voids content near the design. The following three samples had an air voids content of near 5.5 percent. The binder content for these samples was approximately 0.4 percent lower than for the first samples. Low asphalt content hinders compaction and likely caused the air voids to be high. The first three samples were taken on 24 July 2013. The last three samples were taken on 13 and 14 August 2013. These dates represent the beginning and end of production on the project. The difference in air voids content may be

Figure 21. Average G_{se} for Columbus AFB surface mix specimens.

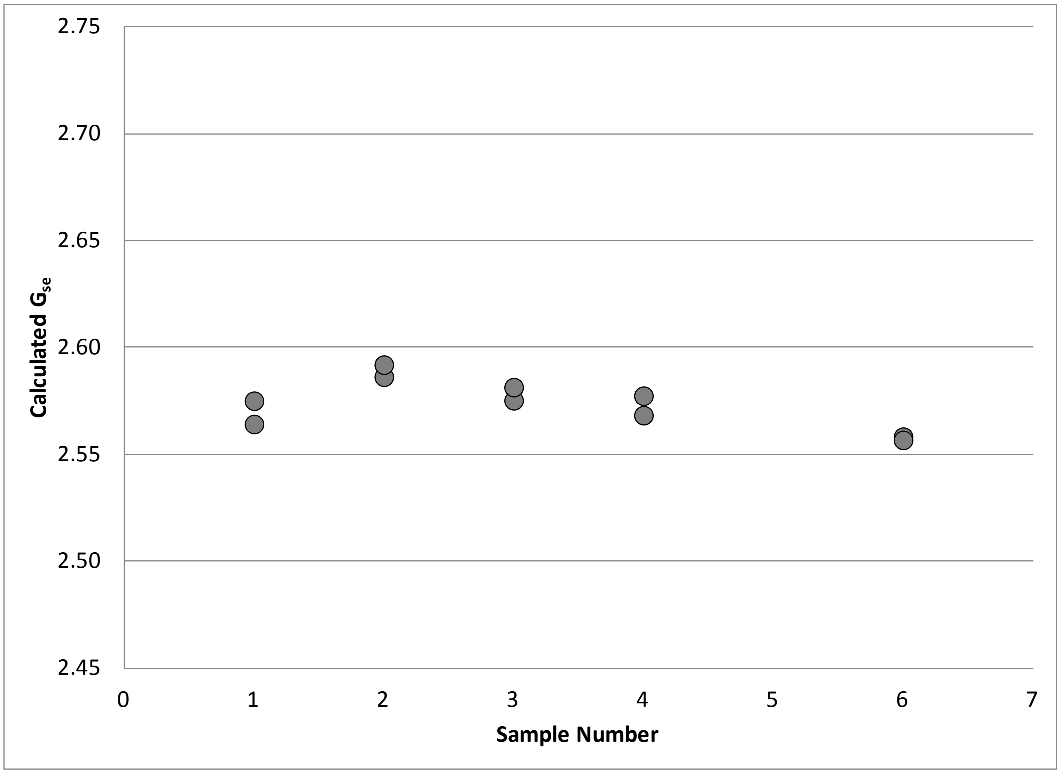
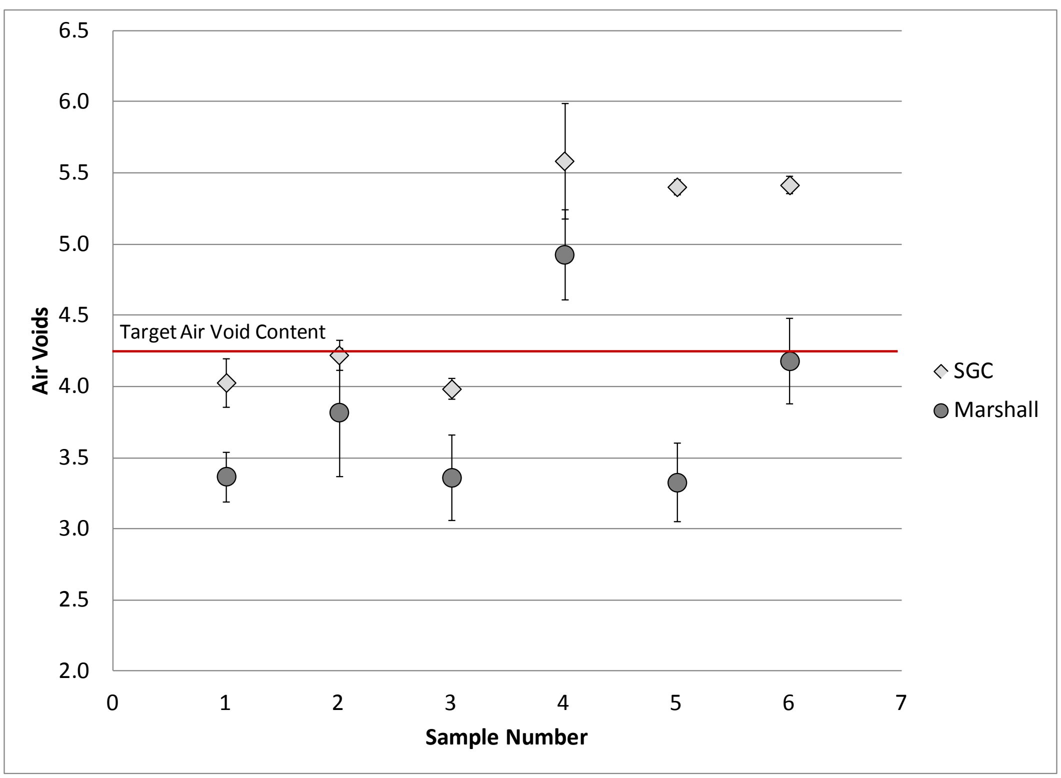


Figure 22. Average air voids content of Columbus AFB surface mix specimens.



related to slight changes in the mixture produced at the plant throughout the project. These samples do not necessarily represent the contractor's ability to produce the designed mixture. Some variability is expected to result from the sampling and testing procedures used to collect the mixture.

The air voids content for specimens compacted by the SGC was consistently higher than the air voids content measured on specimens compacted using the manual Marshall hammer. For this mixture, 75 gyrations in the SGC achieved the design mixture density for the first three samples. The air voids contents for specimens compacted using the Marshall hammer were below the target value of 4.0 percent. The last three samples had low asphalt content and did not achieve target density.

On two samples taken from this project, the compaction effort was varied for the SGC to produce a compaction curve. For these samples, two specimens were compacted using 55 gyrations, two using 75 gyrations, and two using 95 gyrations. The average air voids content of specimens from these samples is shown in Figure 23 along with the asphalt content for the sample. Increasing the asphalt content by 0.3 percent resulted in approximately 1.0 percent reduction in air voids content for the compacted specimens. The data indicate that designing this mixture using the Marshall method would have resulted in a slight decrease (~0.2 percent) in design asphalt content.

Figure 23. Compaction curves for Columbus AFB surface mix specimens.

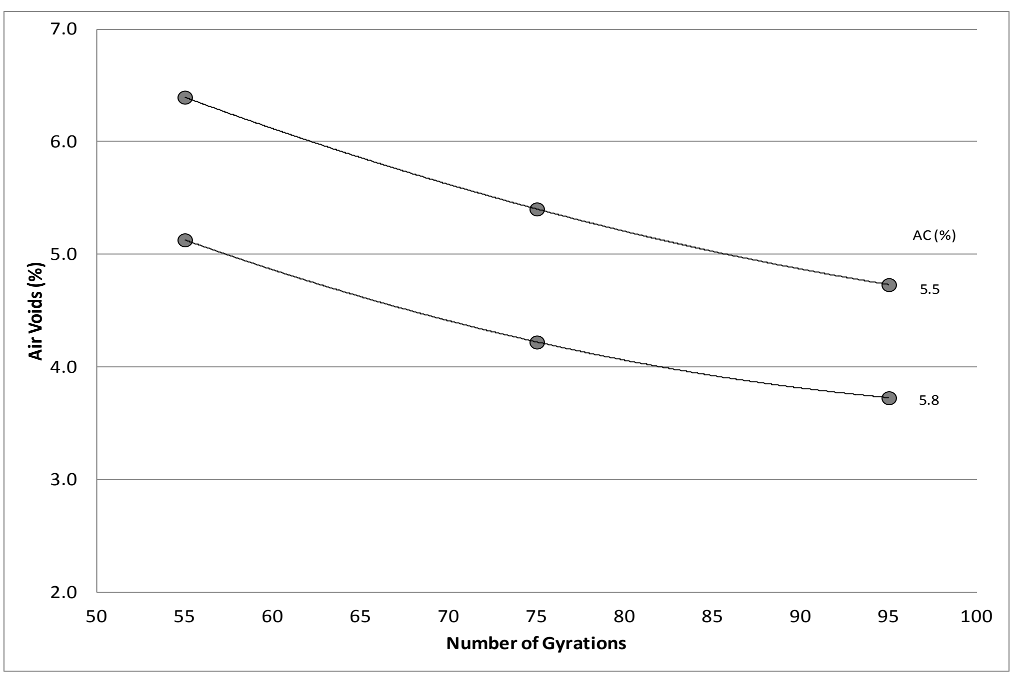


Figure 24 provides stability and flow data for Marshall specimens. The average stability value was 4,879 lb, and the average flow was 15. These values indicate an acceptable asphalt mixture. Volumetric properties and stability and flow values for each specimen are given in Table 5.

Figure 24. Marshall stability and flow for Columbus AFB surface mix specimens.

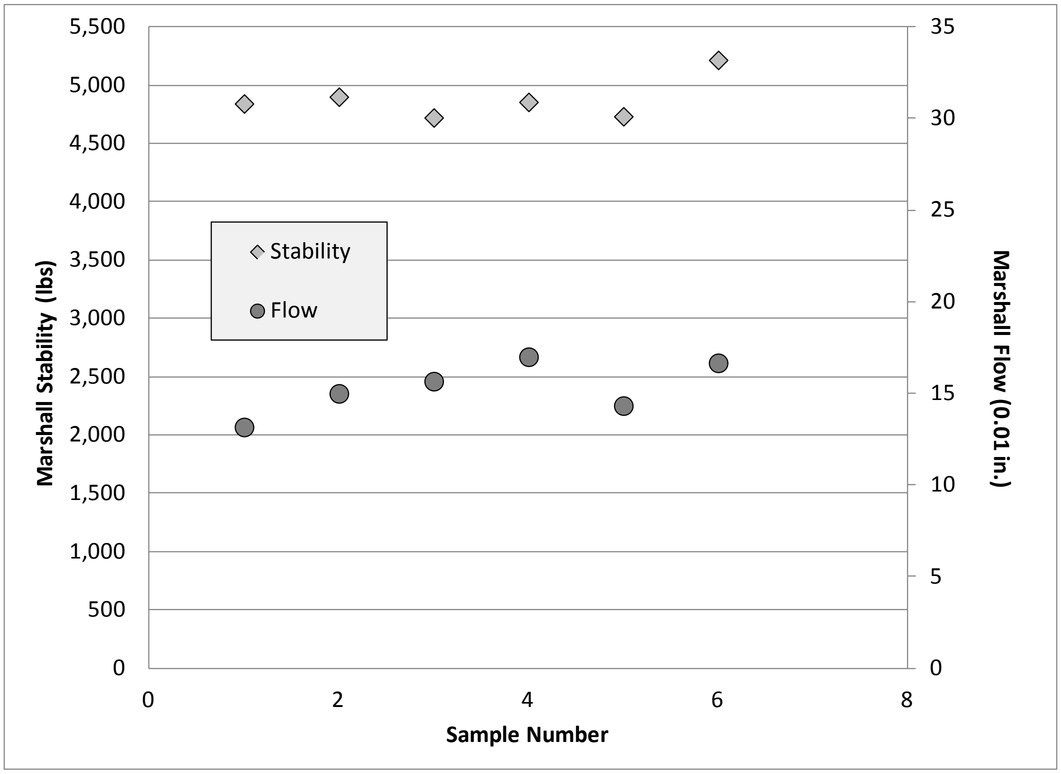


Table 5. Columbus AFB data for Marshall surface mix specimens.

Sample #	Specimen #	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	Stability	Flow
1	M207	5.69	2.295	2.374	3.3	12.9	74.1	4,844	12
	M208	5.69	2.298	2.374	3.2	12.8	75.0	4,916	16
	M209	5.69	2.299	2.374	3.2	12.8	75.0	4,659	11
	M210	5.69	2.294	2.374	3.4	12.9	73.9	4,947	14
	M211	5.69	2.288	2.374	3.6	13.2	72.4	4,855	15
	M212	5.69	2.292	2.374	3.5	13.0	73.4	4,834	11
2	M213	5.83	2.293	2.370	3.2	13.1	75.3	4,556	15
	M214	5.83	2.266	2.370	4.4	14.1	69.0	4,803	16
	M215	5.83	2.268	2.370	4.3	14.1	69.4	5,379	17
	M216	5.83	2.287	2.370	3.5	13.4	73.7	4,834	14
	M217	5.83	2.284	2.370	3.6	13.5	73.1	5,071	12
	M218	5.83	2.279	2.370	3.8	13.7	71.9	4,762	16

Sample #	Specimen #	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	Stability	Flow
3	M219	5.78	2.288	2.371	3.5	13.3	73.5	4,556	14
	M220	5.78	2.297	2.371	3.1	12.9	75.8	4,772	14
	M221	5.78	2.299	2.371	3.0	12.8	76.3	5,637	16
	M222	5.78	2.296	2.371	3.2	13.0	75.4	5,112	18
	M223	5.78	2.289	2.371	3.5	13.2	73.8	3,527	16
	M224	5.78	2.280	2.371	3.8	13.6	71.7	4,731	16
4	M237	5.53	2.257	2.379	5.1	14.2	63.9	4,721	17
	M238	5.53	2.261	2.379	5.0	14.1	64.6	4,536	16
	M239	5.53	2.265	2.379	4.8	13.9	65.4	5,019	16
	M240	5.53	2.274	2.379	4.4	13.5	67.4	4,752	17
	M241	5.53	2.252	2.379	5.4	14.4	62.8	4,937	18
	M242	5.53	2.264	2.379	4.9	14.0	65.1	5,174	18
5	M243	5.50	2.299	2.371	3.0	12.6	76.1	4,464	13
	M244	5.50	2.281	2.371	3.8	13.3	71.4	4,433	13
	M245	5.50	2.292	2.371	3.3	12.9	74.2	4,824	17
	M246	5.50	2.296	2.371	3.1	12.7	75.2	4,638	12
	M247	5.50	2.294	2.371	3.2	12.8	74.7	4,978	16
	M248	5.50	2.289	2.371	3.5	13.0	73.4	5,060	15
6	M249	5.47	2.291	2.381	3.8	12.8	70.6	5,132	18
	M250	5.47	2.283	2.381	4.1	13.2	68.7	5,678	19
	M251	5.47	2.287	2.381	4.0	13.0	69.4	5,534	16
	M252	5.47	2.277	2.381	4.4	13.4	67.2	5,174	13
	M253	5.47	2.282	2.381	4.2	13.2	68.3	5,102	18
	M254	5.47	2.272	2.381	4.6	13.6	66.1	4,680	16
	Average	5.63	2.284	2.375	3.8	13.3	71.3	4,879	15

SGC specimens were tested in the APA using two different loading conditions. The test temperature was set to 64°C, the high PG grade temperature for the climate. The actual PG grade of the binder used for the surface mix was 76-22, indicating a modified binder was selected for enhanced rutting performance. The first set of APA tests applied a 250-lb load with a hose pressure of 250 psi. The second set of tests applied a 100-lb load with a hose pressure of 100 psi. The purpose of the second test was to provide data to compare the mixture rutting potential to that of mixtures presented in literature where the loading conditions are set to represent highway truck traffic. Testing was performed until 8,000 cycles were applied or the rut depth exceeded 12 mm. The six specimens from each sample were tested together. The accumulated rut depth for all specimens is shown in Figures 25 and 26.

Figure 25. 250 psi APA data for Columbus AFB surface mix specimens.

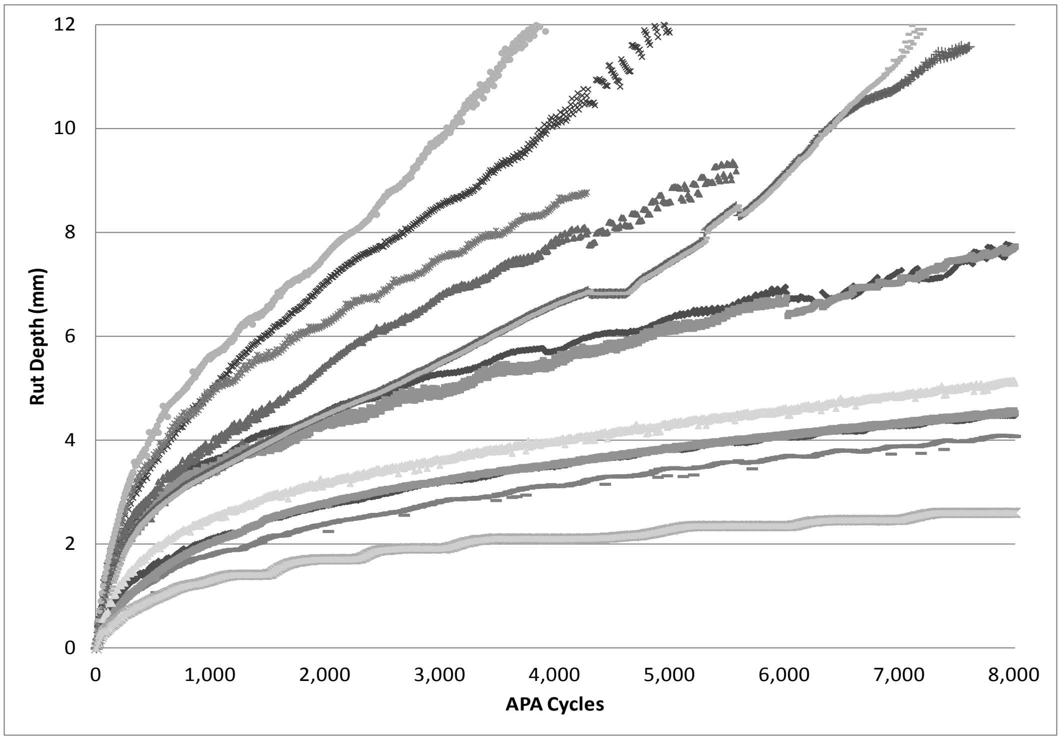


Figure 26. 100 psi APA data for Columbus AFB surface mix specimens.

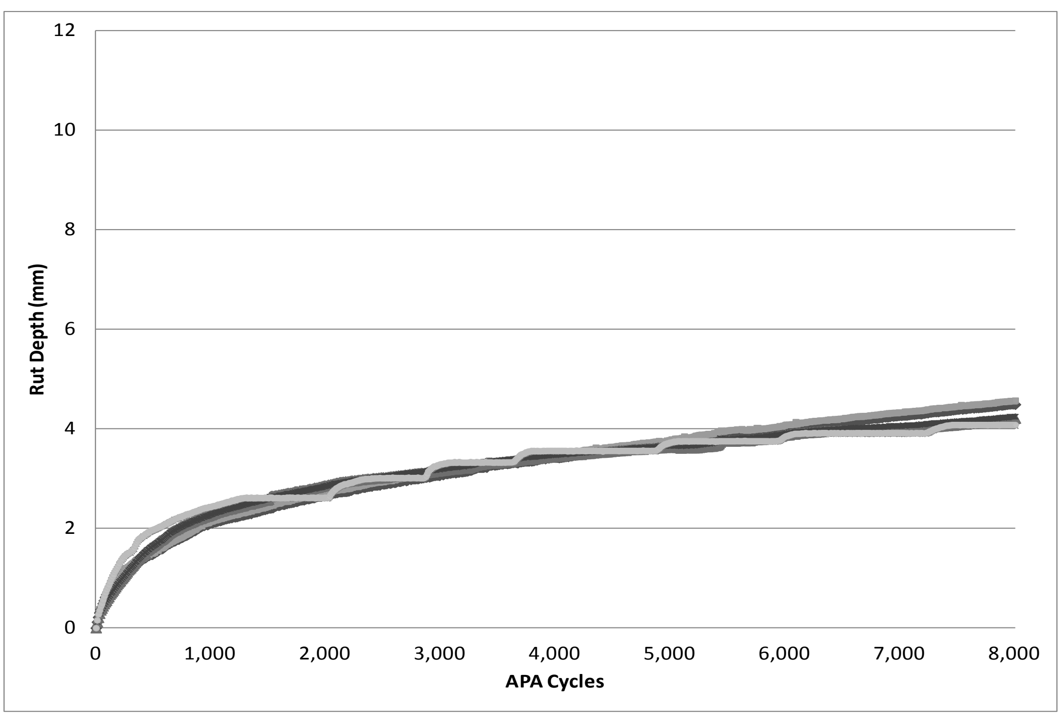


Table 6 provides the rut depth after 4,000 APA cycles for each specimen along with volumetric properties. For the tests using 250-lb load and 250-psi hose pressure, the average rut depth after 4,000 APA cycles was 5.9 mm for this mixture. By comparison to mixtures tested by Rushing et al. (2012), this mixture is of good quality in terms of rutting. The average rut depth after 4,000 APA cycles for the tests performed using 100-lb load and 100-psi hose pressure was 3.5 mm. These results also indicate that the mixture is good quality in terms of rutting based on studies available in literature.

Table 6. Columbus AFB data for SGC surface mix specimens.

Sample #	Specimen #	Number of Gyrations	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	APA Rut Depth After 4,000 Cycles
1	G207	75	5.69	2.272	2.374	4.3	13.8	68.8	3.4[1]
	G208	75	5.69	2.277	2.374	4.1	13.6	69.9	3.5[1]
	G209	75	5.69	2.277	2.374	4.1	13.6	69.9	3.4[1]
	G210	75	5.69	2.283	2.374	3.8	13.4	71.3	3.5[1]
	G211	75	5.69	2.280	2.374	4.0	13.5	70.6	3.5[1]
	G212	75	5.69	2.282	2.374	3.9	13.4	71.1	3.6[1]
2	G213	55	5.83	2.246	2.370	5.2	14.9	64.9	8.6
	G214	55	5.83	2.251	2.370	5.0	14.7	65.9	8.8
	G215	75	5.83	2.268	2.370	4.3	14.1	69.5	5.7
	G216	75	5.83	2.272	2.370	4.1	13.9	70.2	5.5
	G217	95	5.83	2.277	2.370	3.9	13.7	71.4	4.9
	G218	95	5.83	2.286	2.370	3.5	13.4	73.7	4.9
3	G219	75	5.78	2.275	2.371	4.1	13.8	70.4	7.9
	G220	75	5.78	2.280	2.371	3.9	13.6	71.5	10.2
	G221	75	5.78	2.278	2.371	4.0	13.7	71.1	8.5
	G222	75	5.78	2.276	2.371	4.0	13.7	70.7	12.6
	G223	75	5.78	2.277	2.371	4.0	13.7	70.8	6.6
	G224	75	5.78	2.277	2.371	4.0	13.7	70.9	6.6
4	G237	75	5.53	2.224	2.379	6.5	15.5	57.7	3.1
	G238	75	5.53	2.243	2.379	5.7	14.7	61.2	3.5
	G239	75	5.53	2.247	2.379	5.6	14.6	61.8	3.6
	G240	75	5.53	2.247	2.379	5.6	14.6	61.8	4.0
	G241	75	5.53	2.251	2.379	5.4	14.4	62.7	2.1
	G242	75	5.53	2.243	2.379	5.7	14.7	61.1	2.1

Sample #	Specimen #	Number of Gyrations	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	APA Rut Depth After 4,000 Cycles
5	G243	55	5.50	2.215	2.371	6.6	15.8	58.5	Not tested
	G244	55	5.50	2.223	2.371	6.2	15.5	59.7	Not tested
	G245	75	5.50	2.242	2.371	5.4	14.8	63.2	Not tested
	G246	75	5.50	2.243	2.371	5.4	14.7	63.5	Not tested
	G247	95	5.50	2.262	2.371	4.6	14.0	67.2	Not tested
	G248	95	5.50	2.255	2.371	4.9	14.3	65.8	Not tested
6	G249	75	5.47	2.253	2.381	5.4	14.3	62.3	Not tested
	G250	75	5.47	2.252	2.381	5.4	14.4	62.1	Not tested
	G251	75	5.47	2.252	2.381	5.4	14.3	62.2	Not tested
	G252	75	5.47	2.254	2.381	5.3	14.3	62.6	Not tested
	G253	75	5.47	2.253	2.381	5.4	14.3	62.3	Not tested
	G254	75	5.47	2.250	2.381	5.5	14.4	61.7	Not tested
	Average[2]		5.62	2.262	2.376	4.8	14.1	66.2	5.9

[1] APA tests performed at 100-psi hose pressure/100-lb load.

[2] Excludes specimens compacted to 55 or 95 gyrations and specimens tested at 100-psi hose pressure/100-lb load.

3.4.2 Base mixture

The base mixture had a maximum aggregate size of 0.75 in. (gradation 2), used 20 percent reclaimed asphalt concrete (RAP), and the binder was a PG 67-22. The design binder content of the base mixture was 5.9 percent to achieve a target air voids content of 4.0 percent when designed using 75 gyrations of the SGC. The mixture included 20 percent RAP, the maximum amount allowed for non-surface mixtures without changes in binder selection. The percent binder in the RAP was 5.0 percent. The percent binder added to the mixture was 4.9 percent to achieve the target total binder content of 5.9 percent. The percent natural sand was 13 percent. The fine aggregate angularity was 43.1 percent, slightly below the minimum specified value of 45 percent. Figure 27 shows the gradation of the mixture and pertinent properties that were supplied by the contractor.

Figure 28 shows the calculated G_{se} for each sample. The average G_{se} value for the base aggregates was 2.563. This value is near the G_{se} value of 2.556 reported in the contractor's mixture design for the base aggregates.

Figure 27. Aggregate blend for Columbus AFB base mixture.

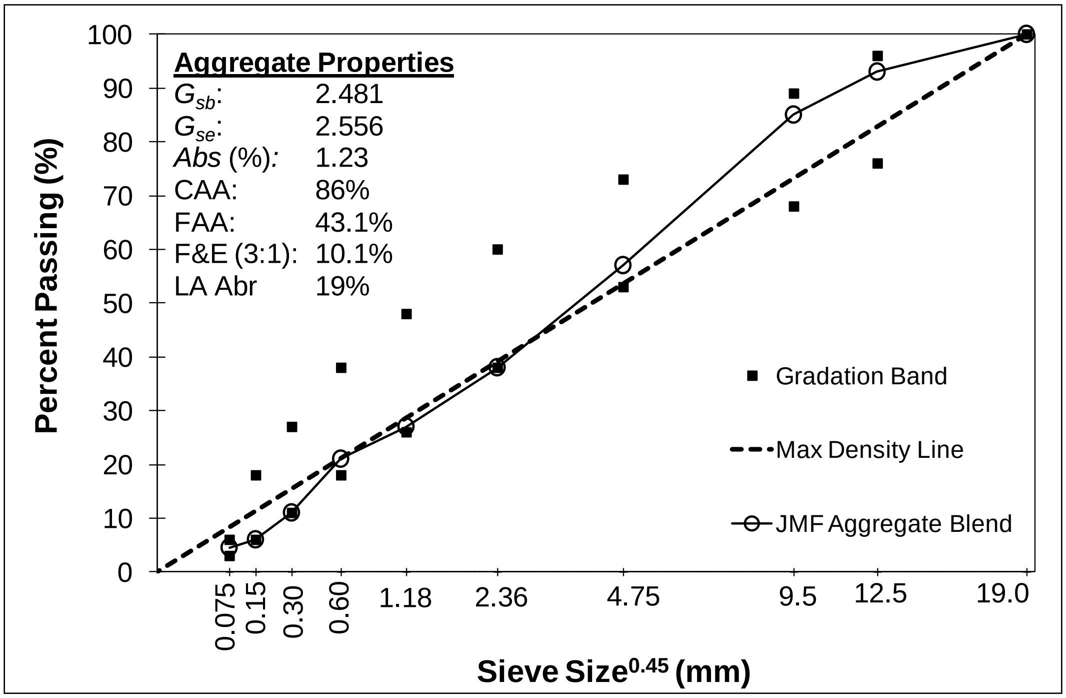


Figure 28. Average G_{se} for Columbus AFB base mix specimens.

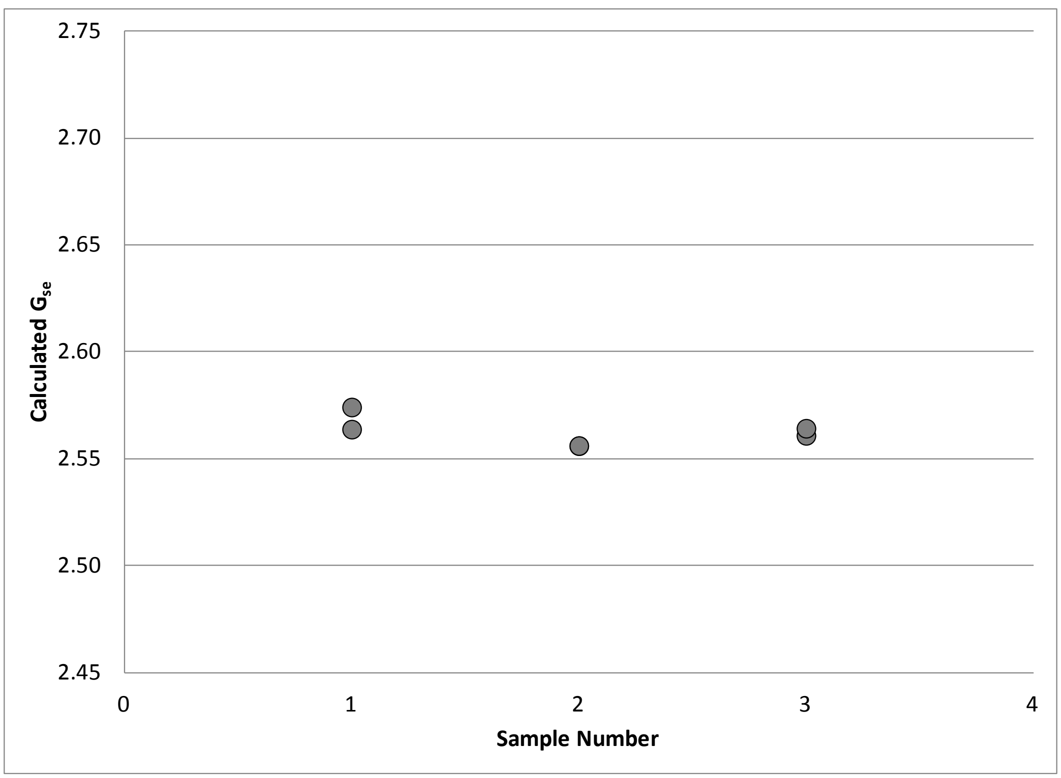


Figure 29 provides the average and standard deviation of the air voids content for six specimens of each of the three samples taken from the base mixture. The air voids content for specimens compacted by the SGC was similar to the air voids content measured on specimens compacted using the manual Marshall hammer for two of the three samples. The first sample shows higher than expected variability for the Marshall specimens. Given the limited data, it is expected that the design asphalt content would be similar to that determined by the SGC, if the Marshall method had been used. For the one mixture produced with three different compaction efforts (55, 75, 95 gyrations), the data (Figure 30) show that the target air voids content of 4.0 percent is achieved when applying 75 gyrations at the design asphalt content.

Figure 31 provides stability and flow data for Marshall specimens. The average stability value was 5,094 lb, and the average flow was 13. These values indicate an acceptable asphalt mixture. Volumetric properties and stability and flow values for each specimen are given in Table 7.

Figure 29. Average air voids content of Columbus AFB base mix specimens.

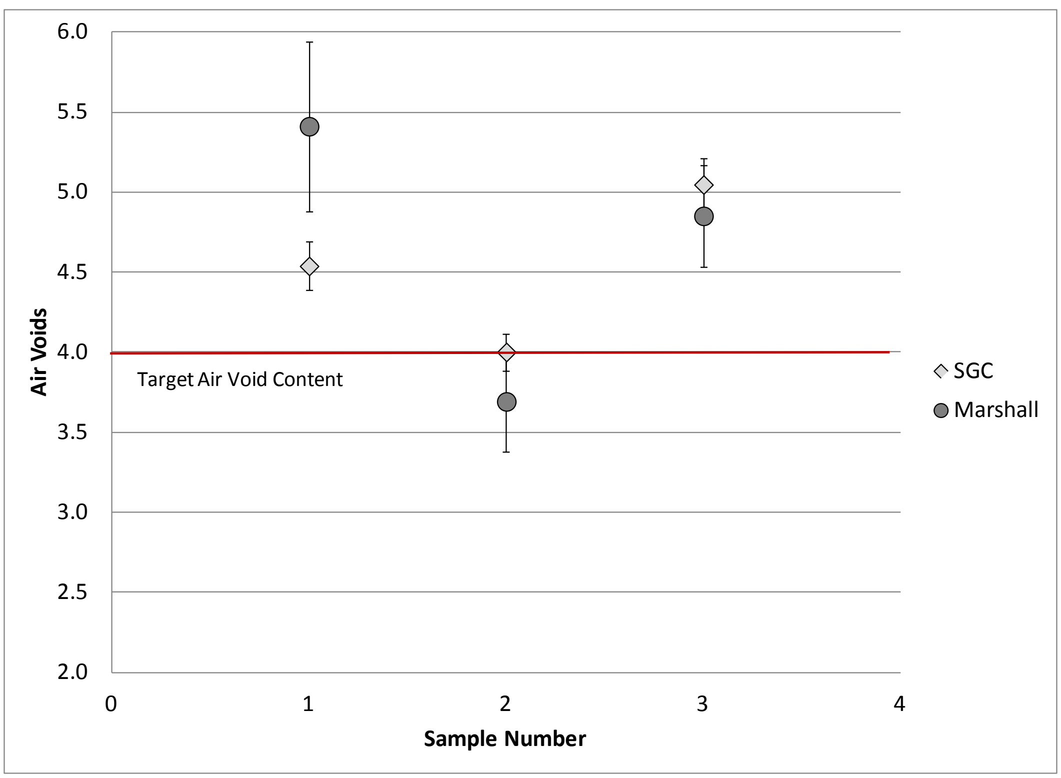


Figure 30. Compaction curve for Columbus AFB base mix specimens.

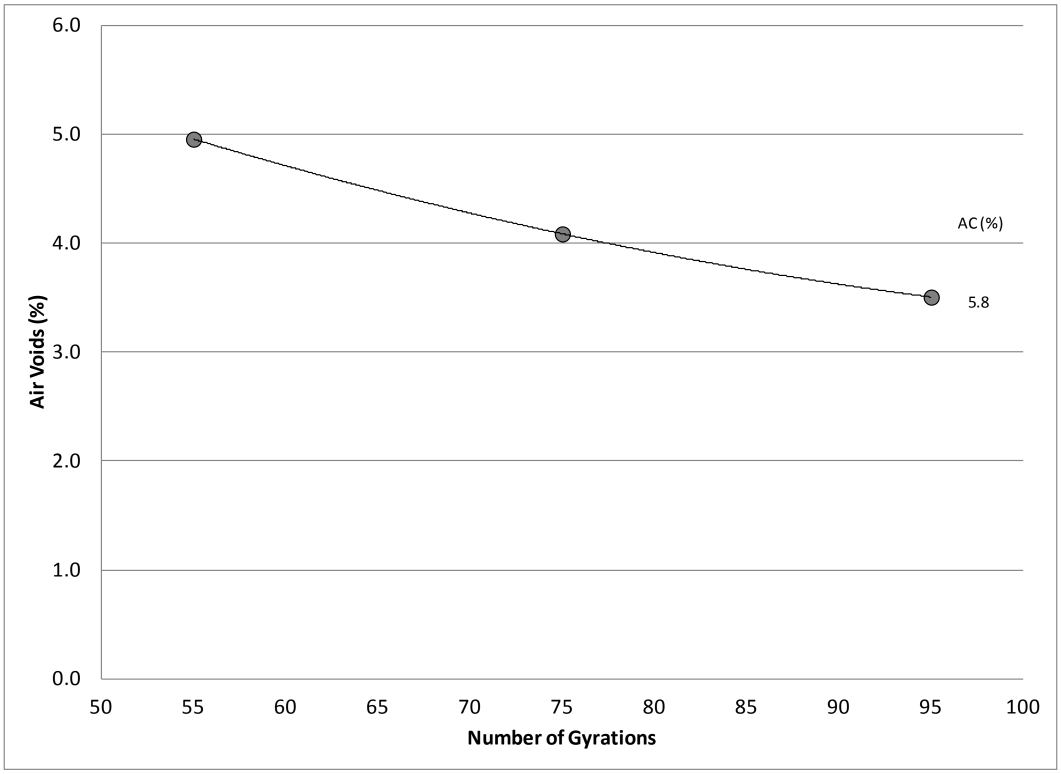


Figure 31. Marshall stability and flow for Columbus AFB base mix specimens.

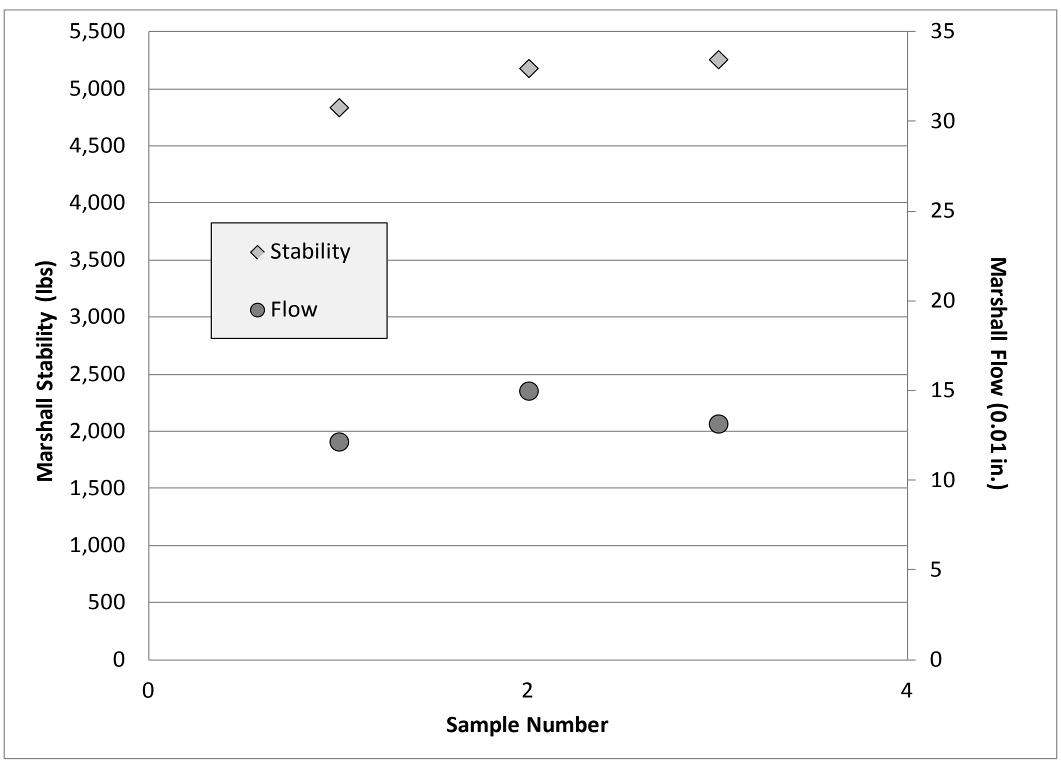


Table 7. Columbus AFB data for Marshall base mix specimens.

Sample #	Specimen #	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	Stability	Flow
1	M201	5.79	2.239	2.371	5.6	15.1	63.1	5,122	12
	M202	5.79	2.239	2.371	5.6	15.1	63.2	4,813	13
	M203	5.79	2.224	2.371	6.2	15.7	60.5	4,278	13
	M204	5.79	2.251	2.371	5.1	14.7	65.5	4,968	12
	M205	5.79	2.243	2.371	5.4	15.0	63.9	5,009	10
	M206	5.79	2.261	2.371	4.6	14.3	67.5	4,844	13
2	M225	5.80	2.292	2.371	3.3	13.1	74.6	5,626	16
	M226	5.80	2.282	2.371	3.7	13.5	72.4	5,132	14
	M227	5.80	2.289	2.371	3.4	13.2	74.0	4,299	16
	M228	5.80	2.281	2.371	3.8	13.5	72.1	4,813	14
	M229	5.80	2.285	2.371	3.6	13.4	72.9	5,740	17
	M230	5.80	2.270	2.371	4.2	14.0	69.7	5,482	13
3	M231	5.92	2.254	2.367	4.8	14.7	67.5	4,999	12
	M232	5.92	2.256	2.367	4.7	14.6	67.9	4,659	14
	M233	5.92	2.255	2.367	4.7	14.6	67.7	6,244	18
	M234	5.92	2.257	2.367	4.6	14.6	68.1	5,277	10
	M235	5.92	2.254	2.367	4.8	14.7	67.5	5,410	14
	M236	5.92	2.237	2.367	5.5	15.3	64.2	4,968	11
	Average	5.84	2.259	2.370	4.7	14.4	67.9	5,094	13

SGC specimens were tested in the APA using two different loading conditions. The test temperature was set to 64°C, the high PG grade temperature for the binder. The first set of tests applied a 250-lb load with a hose pressure of 250 psi. The second set of tests applied a 100-lb load with a hose pressure of 100 psi. The accumulated rut depth for all specimens is shown in Figures 32 and 33.

Table 8 provides the rut depth after 4,000 APA cycles for each specimen. For the tests using 250-lb load and 250-psi hose pressure, the average rut depth after 4,000 APA cycles was 7.2 mm for this mixture, indicating good quality in terms of rutting. The average rut depth after 4,000 APA cycles for the tests performed using 100-lb load, and 100-psi hose pressure was 3.5 mm. These results also indicate that the mixture is good quality.

Figure 32. 250 psi APA data for Columbus AFB base mix specimens.

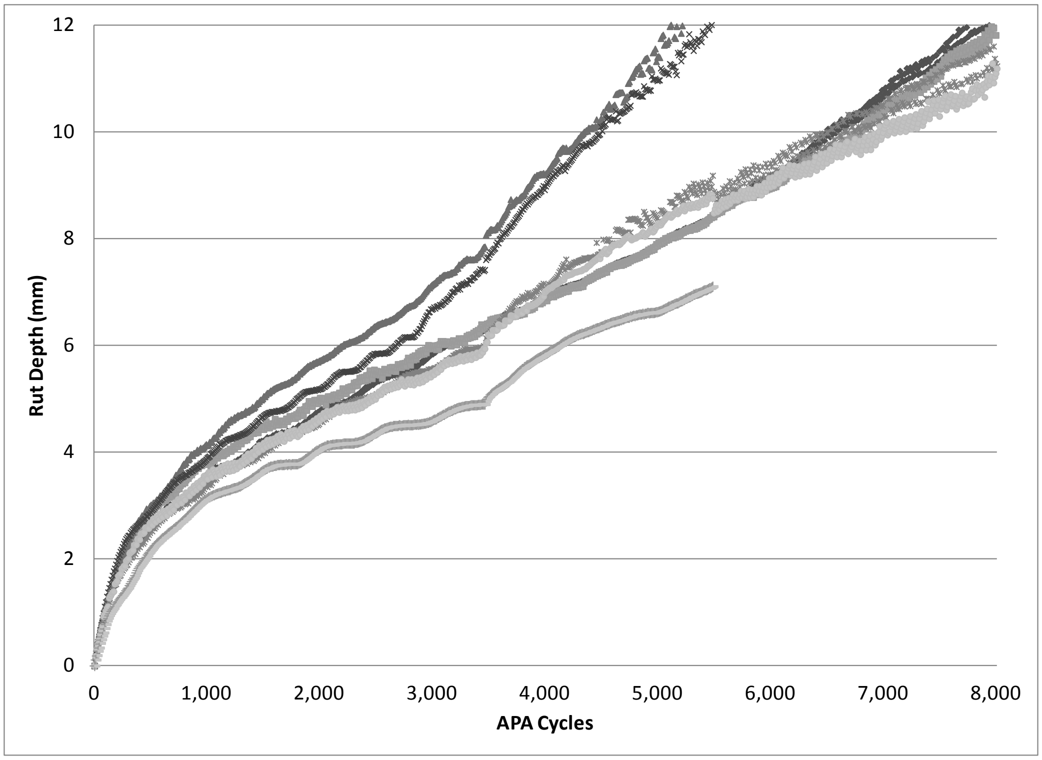


Figure 33. 100 psi APA data for Columbus AFB base mix specimens.

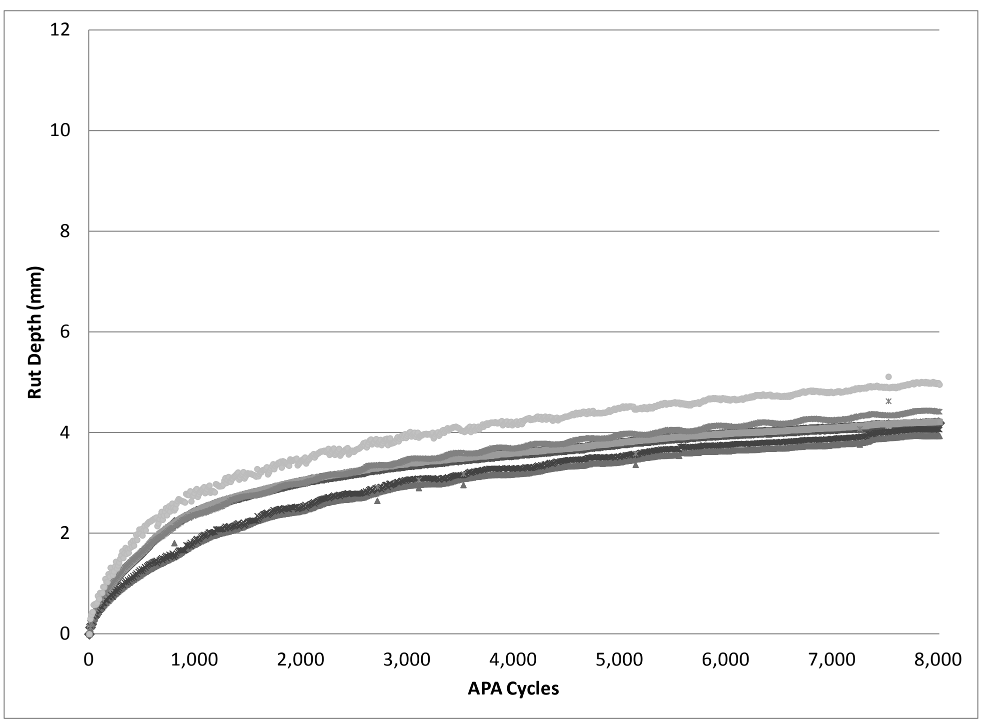


Table 8. Columbus AFB data for SGC base mix specimens.

Sample #	Specimen #	Number of Gyrations	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	APA Rut Depth After 4,000 Cycles
1	G201	75	5.79	2.259	2.371	4.7	14.4	67.1	3.6[1]
	G202	75	5.79	2.266	2.371	4.4	14.1	68.7	3.6[1]
	G203	75	5.79	2.264	2.371	4.5	14.2	68.2	3.2[1]
	G204	75	5.79	2.259	2.371	4.7	14.4	67.2	3.3[1]
	G205	75	5.79	2.267	2.371	4.4	14.1	68.9	3.7[1]
	G206	75	5.79	2.265	2.371	4.5	14.2	68.3	4.2[1]
2	G225	55	5.80	2.253	2.371	5.0	14.6	66.0	4.0
	G226	55	5.80	2.253	2.371	5.0	14.6	66.1	5.5
	G227	75	5.80	2.278	2.371	3.9	13.7	71.3	6.9
	G228	75	5.80	2.274	2.371	4.1	13.8	70.4	6.9
	G229	95	5.80	2.290	2.371	3.4	13.2	74.3	4.1
	G230	95	5.80	2.288	2.371	3.5	13.3	73.7	4.1
3	G231	75	5.92	2.243	2.367	5.3	15.1	65.2	9.2
	G232	75	5.92	2.245	2.367	5.1	15.0	65.7	9.0
	G233	75	5.92	2.245	2.367	5.2	15.0	65.7	7.1
	G234	75	5.92	2.250	2.367	4.9	14.8	66.7	7.0
	G235	75	5.92	2.250	2.367	4.9	14.8	66.7	5.8
	G236	75	5.92	2.252	2.367	4.8	14.7	67.2	5.8
	Average[2]		5.85	2.258	2.369	4.7	14.5	67.7	7.2

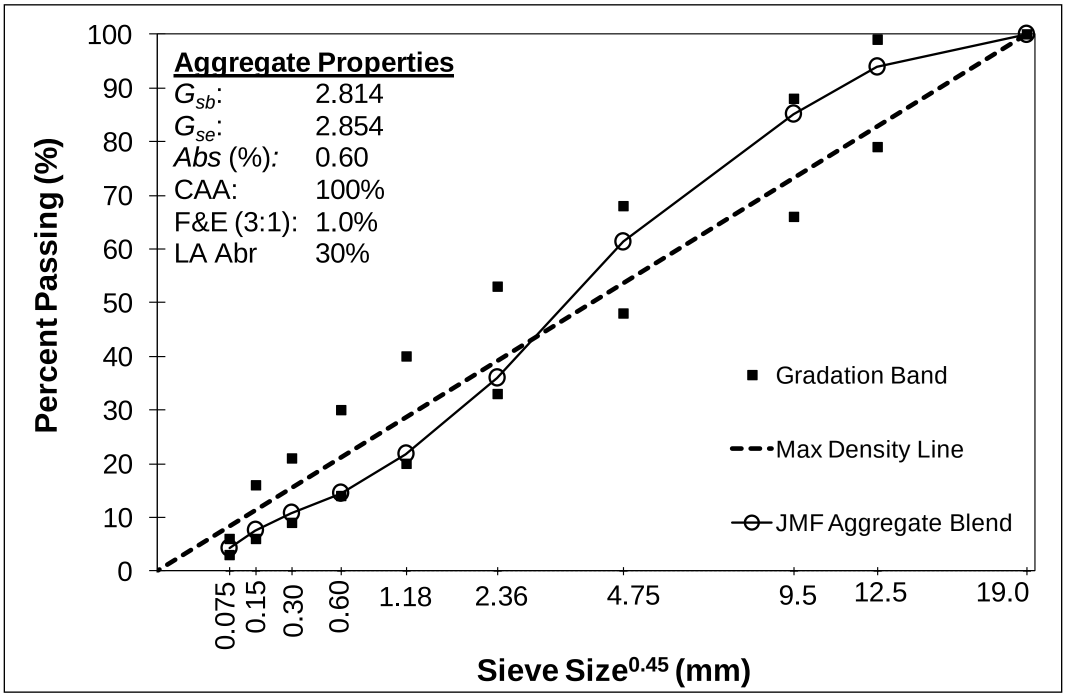
[1] APA tests performed at 100-psi hose pressure/100-lb load.

[2] Excludes specimens compacted to 55 or 95 gyrations.

3.5 Federal Aviation Administration Technical Center, Atlantic City, NJ

HMA was placed at the National Airport Pavement Test Facility (NAPTF) in Atlantic City, NJ on 13 November 2013. The mixture was designed according to Federal Aviation Administration (FAA) advisory circular 150/5370-10F, *Standards for specifying construction of airports*. (FAA 2009). The mixture was designed for a 12.5 mm-nominal maximum aggregate size surface mixture using the 75-blow manual Marshall method. The design binder content was 5.0 percent to achieve 3.4 percent air voids. The binder was a modified PG 76-22. Figure 34 shows the gradation of the mixture and pertinent properties that were supplied by the contractor.

Figure 34. Aggregate blend for NAPTF mixture.



A sample of paving mixture was taken from delivery trucks at the paving site inside the NAPTF and brought to the adjacent asphalt laboratory. The material was weighed into shallow pans with the appropriate mass to prepare specimens in the SGC and placed into ovens at the mixing temperature (320°F) for approximately 30 min to allow the mixture to achieve the desired compaction temperature. Specimens were then compacted using 75 gyrations of the SGC. The compacted specimens and the remaining material sampled from the trucks were shipped to the ERDC laboratory, where the TMD was determined from the unused sample and the air voids content of the compacted specimens was determined. Volumetric properties from the compacted specimens are given in Table 9.

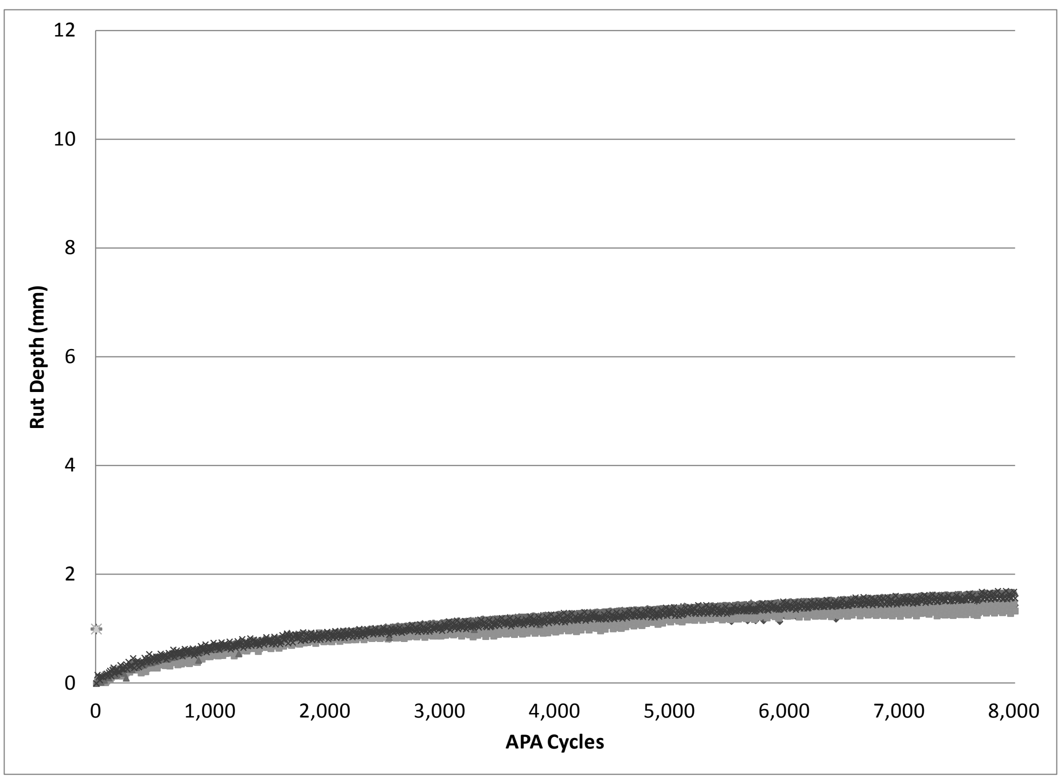
Table 9. NAPTF data for SGC surface mix specimens.

Specimen	Number of Gyrations	Asphalt Content (%)	G_{mb}	G_{mm}	V_a	VMA	VFA	APA Rut Depth After 4,000 Cycles	Indirect Tensile Strength (psi)
G301	75	5.0	2.582	2.637	2.1	14.1	85.1	2.7	--
G302	75	5.0	2.566	2.637	2.7	14.6	81.5	3.1	--
G303	75	5.0	2.577	2.637	2.3	14.2	83.4	3.3	--
G304	75	5.0	2.575	2.637	2.4	14.3	83.5	3.6	--
G305	75	5.0	2.579	2.637	2.2	14.2	84.5	--	63
G306	75	5.0	2.576	2.637	2.3	14.3	83.7	--	60
Average	75	5.0	2.577	2.637	2.3	14.3	83.9	3.2	62

The average air voids for the six specimens compacted in the SGC was 2.3 percent. This value was below the air voids content of 3.4 percent produced by the Marshall design. No Marshall specimens were prepared from the sampled material. The asphalt content was assumed to be 5.0 percent, the same as the design. However, the asphalt content was not measured. Data indicate that the SGC produces specimens at lower air voids content than targeted for this mixture. The VMA of the SGC specimens is also lower, indicating greater densification in the SGC than with the manual Marshall compaction.

Four of the six SGC specimens were tested in the APA. The test temperature was set to 64°C, the high PG grade temperature for the selected climate. The mixture was prepared using a PG 76-22 modified binder that is intended to improve rutting performance. The APA tests applied a 250-lb load with a hose pressure of 250 psi. Testing was performed until 8,000 cycles were applied or the rut depth exceeded 12 mm. The accumulated rut depth is shown in Figure 35.

Figure 35. NAPTF APA data.



The remaining two SGC specimens were tested to determine indirect tensile strength according to a method described in a draft FAA specification for SGC mixture design. First, the specimens were cut on each end to reduce the height to 100 mm. Next, they were placed into a water bath at 40°C for at least 4 hr. The specimens were placed into the load frame and compressed at a rate of 50 mm/min. The peak load was used to determine indirect tensile strength.

Table 9 provides the rut depth after 4,000 APA cycles or the indirect tensile strength. The average rut depth after 4,000 APA cycles was 3.2 mm for this mixture. The average indirect tensile strength was 129 psi. By comparison to mixtures tested by Rushing et al. (2012), this mixture is of good quality in terms of rutting.

4 Discussion

The primary objective of the work described in this report was to determine if using a specification requiring 75 gyrations of the SGC for HMA compaction produces a different product than using a specification requiring 75 blows of a manual Marshall hammer for HMA compaction. Additional objectives were to determine if a contractor's percent payment is affected by the compaction option selected in the specification, and to evaluate a laboratory performance test protocol for SGC-compacted specimens. These objectives are discussed in relation to the data collected for each asphalt mixture in the following paragraphs.

4.1 Site 1: March Air Reserve Base, Moreno Valley, CA

The measured air voids content of the specimens produced using 75 gyrations in the SGC was consistently higher than that of the specimens produced using 75 blows of the manual Marshall hammer. The average difference in air voids content (excluding sample 6) was 1.6 percent. Eight specimens (two each from four samples) were compacted using 95 gyrations of the SGC. These specimens had an average air voids content 0.75 percent higher than the Marshall specimens produced from the same sample. For this particular mixture, the number of gyrations providing equivalent density to 75 blows of the Marshall hammer was greater than 95. If 75 gyrations in the SGC had been used to design the mixture, the selected asphalt content would have been higher than that selected from the Marshall design because more binder would be needed to fill the voids and lower the air voids content. APA data suggest that the rutting potential of the mixture is relatively high, and adding extra binder to the mixture would likely reduce rutting performance. Rushing et al. (2012) recommended a criterion of less than 10-mm rutting after 4,000 APA cycles for accepting an asphalt mixture. This mixture averaged 10.6-mm rutting after 4,000 APA cycles.

4.2 Site 2: ERDC, Vicksburg, MS

The mixture designed using 75 gyrations in the SGC had a design asphalt content was 5.3 percent. Designing the mixture using 75 blows from a manual Marshall hammer resulted in a design asphalt content of 5.1 percent. Compaction data from this mixture indicate that using the SGC to produce the design results in an increase in design asphalt content of approximately 0.25 percent. APA tests on this mixture produced an average rut depth of 10.5 mm after 4,000 cycles, indicating marginal quality in terms of rutting.

4.3 Site 3: Monroe County, MS

The air voids content for specimens compacted by the SGC was similar to the air voids content measured on specimens compacted using the manual Marshall hammer. For this mixture, using the SGC or Marshall method to design the mixture should result in the same design asphalt content. APA tests on this mixture produced an average rut depth of 6.2 mm after 4,000 cycles, indicating good quality in terms of rutting.

4.4 Site 4: Columbus Air Force Base, Columbus, MS

Two mixtures were used during paving at Columbus AFB. The design air voids content was 4.0 percent in each case. The air voids content for specimens compacted by the SGC was consistently higher than the air voids content measured on specimens compacted using the manual Marshall hammer. For the surface mixture, 75 gyrations in the SGC achieved the design mixture density for the first three samples. The air voids contents for specimens compacted using the Marshall hammer were below the target value of 4.0 percent. The last three samples had low asphalt content and did not achieve target density. The data indicate that designing this mixture using the Marshall method would have resulted in a slight decrease (~0.2 percent) in design asphalt content. The average rut depth after 4,000 APA cycles was 5.9 mm for this mixture, indicating good quality in terms of rutting.

For the base mixture produced on this project, the air voids content for specimens compacted by the SGC was similar to the air voids content measured on specimens compacted using the manual Marshall hammer for two of the three samples. The first sample shows higher than expected variability for the Marshall specimens. Given the limited data, it is expected that the design asphalt content would be similar to that determined by the SGC if the Marshall method had been used. The average rut depth after 4,000 APA cycles was 7.2 mm for this mixture, indicating good quality in terms of rutting.

4.5 Site 5: NAPTF, Atlantic City, NJ

The average air voids content for the six specimens compacted in the SGC was 2.3 percent. This value was below the air voids content of 3.4 percent produced by the Marshall design. Data indicate that the SGC produces specimens at lower air voids content than targeted for this mixture. If the mixture had been designed using 75 gyrations of the SGC, the asphalt content would be reduced to result in higher air voids content. The average rut depth after 4,000 APA cycles was 3.2 mm for this mixture. The average indirect tensile strength was 129 psi. These values indicate good quality in terms of rutting.

4.6 Summary

Table 10 summarizes the difference in asphalt content produced by using the SGC to design mixtures compared to the manual Marshall hammer. Three of the six mixtures from this study would require additional binder if the design had been produced using the SGC. While the increase in binder content is likely small, the use of additional binder can increase the cost of the mixture and increase rutting potential. On the other hand, the durability of the mixture is improved by adding additional binder. As long as rutting is not prevalent on SGC-designed mixtures, using the 75 gyration design method should produce quality paving materials. An appropriate method to reduce the likelihood of using rut-prone mixtures is to include a performance test such as the APA in mixture design specifications.

Table 10. Summary of project data.

Project Location	Change in Binder Content When Using SGC
March Air Reserve Base	Increase
ERDC	Increase
Monroe County	No change
Columbus Air Force Base	
Surface	Increase
Base	No change
NAPTF	Decrease

Data from the study also indicate the SGC is capable of reducing the variability of measured air voids content for specimens of a given mixture compared to Marshall compaction. A typical standard deviation in air voids content for a set of six Marshall specimens is approximately 0.5 percent. The same mixture can be compacted using the SGC with a typical standard deviation of below 0.2 percent in many cases. The current UFGS paving specification includes payment to the contractor based on the average air voids content measured for a defined lot of material, among other items. Even though the standard deviation of the air voids content is different for the SGC and Marshall hammer, the percent payment to the contractor is not affected because the specification only includes average values, not individual measurements or variability. The alternative specification using the SGC does not affect contractor payment for a given quality of work.

Finally, the APA data indicate it can be an effective tool for assessing rutting performance during HMA mixture design. Only one mixture, the March Air Reserve Base mixture, had APA rutting performance that would have been deemed unsuitable according to the proposed threshold value. The mixtures prepared using polymer-modified binders had exceptional rutting performance according to APA data. Additional data should be collected to recommend a performance test and associated criteria for screening mixtures.

5 Conclusions and Recommendations

5.1 Conclusions

The following conclusions resulted from sampling and testing HMA during production to determine compaction characteristics using both the SGC and the manual Marshall hammer.

- Six paving mixtures produced in asphalt plants were sampled to compact specimens using 75 blows of the manual Marshall hammer and 75 gyrations of the SGC. Three of the mixtures had higher air voids content when compacted in the SGC. Two had nearly equal air voids content, and one had lower air voids content.
- The standard deviation of air voids content for a group of specimens compacted using the SGC was typically less than half of that from specimens compacted using the manual Marshall hammer.
- Four of the six mixtures had good rutting performance according to APA test results when compared to values presented in literature. The March Air Reserve Base and ERDC mixtures had questionable rutting performance. The APA provides a simple performance index to assess rutting potential.
- Using the SGC to prepare specimens for quality control and quality assurance is not expected to change the payment to a contractor for a given quality of work when using the method described in UFGS 32-12-15.

5.2 Recommendations

Data collected during this study do not indicate any major change in the quality of asphalt concrete designed and produced using an alternative specification based on SGC compaction. Minor changes in the design binder content are expected to result for some mixtures when the SGC is used in lieu of Marshall compaction. Projects using the SGC specification should be documented and monitored to ensure that no type of pavement distress becomes more prevalent for paving mixtures designed with the new method. A performance test should be considered for the SGC specification to provide additional evidence of acceptable quality. No critical findings from this study would preclude the full implementation and use of the SGC to design and control the quality of HMA for airfield pavements.

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Appendix A: Data Tables

Table A1. March Air Reserve Base Marshall data.

Specimen No.	Binder Content (%)	Sample Mass (g)			Volume (cc)	Specific Gravity		Air Voids (%)	VMA (%)	% Voids Filled	Unit Weight (lb/ft^3)
		Dry	In Water	SSD		Actual	Theoretical				
M001	4.74	1199.0	697.1	1200.0	502.9	2.384	2.549	6.5	15.9	68	148.8
M002	4.74	1200.8	702.7	1201.5	498.8	2.407	2.549	5.5	15.1	73	150.2
M003	4.74	1204.2	703.5	1205.6	502.1	2.398	2.549	5.9	15.4	71	149.7
M004	4.74	1199.7	701.1	1200.6	499.5	2.402	2.549	5.8	15.3	72	149.9
M005	4.74	1198.4	705.6	1199.3	493.7	2.427	2.549	4.8	14.4	77	151.5
M006	4.74	1195.0	701.5	1195.5	494.0	2.419	2.549	5.1	14.7	75	150.9
Average	**4.74**	**1199.5**	**701.9**	**1200.4**	**498.5**	**2.406**	**2.549**	**5.6**	**15.1**	**73**	**150.2**
M007	5.27	1203.7	711.6	1204.1	492.5	2.444	2.528	3.3	14.3	87	152.5
M008	5.27	1200.7	711.9	1201.3	489.4	2.453	2.528	3.0	14.0	89	153.1
M009	5.27	1199.6	714.6	1200.0	485.4	2.471	2.528	2.2	13.3	94	154.2
M010	5.27	1204.1	710.9	1204.5	493.6	2.439	2.528	3.5	14.5	86	152.2
M011	5.27	1200.5	711.4	1201.0	489.6	2.452	2.528	3.0	14.0	89	153.0
M012	5.27	1200.8	711.6	1201.2	489.6	2.453	2.528	3.0	14.0	89	153.0
Average	**5.27**	**1201.6**	**712.0**	**1202.0**	**490.0**	**2.452**	**2.528**	**3.0**	**14.0**	**89**	**153.0**
M013	5.18	1206.2	711.7	1206.7	495.0	2.437	2.531	3.7	14.5	84	152.1
M014	5.18	1209.1	718.7	1209.6	490.9	2.463	2.531	2.7	13.5	91	153.7
M015	5.18	1206.6	713.9	1206.9	493.0	2.447	2.531	3.3	14.1	87	152.7
M016	5.18	1208.4	713.3	1208.8	495.5	2.439	2.531	3.6	14.4	85	152.2
M017	5.18	1212.5	719.1	1212.8	493.7	2.456	2.531	3.0	13.8	89	153.3
M018	5.18	1215.4	717.4	1215.7	498.3	2.439	2.531	3.6	14.4	85	152.2
Average	**5.18**	**1209.7**	**715.7**	**1210.1**	**494.4**	**2.447**	**2.531**	**3.3**	**14.1**	**87**	**152.7**
M019	5.18	1217.1	716.3	1217.6	501.3	2.428	2.531	4.1	14.8	82	151.5
M020	5.18	1209.1	715.3	1208.9	493.6	2.450	2.531	3.2	14.0	87	152.9
M021	5.18	1214.9	714.3	1215.6	501.3	2.423	2.531	4.2	14.9	81	151.2
M022	5.18	1207.6	715.5	1208.3	492.8	2.450	2.531	3.2	14.0	88	152.9
M023	5.18	1295.2	767.8	1295.8	528.0	2.453	2.531	3.1	13.9	88	153.1
M024	5.18	1209.1	711.1	1209.6	498.5	2.425	2.531	4.2	14.9	82	151.3
Average	**5.18**	**1225.5**	**723.4**	**1226.0**	**502.6**	**2.438**	**2.531**	**3.7**	**14.4**	**85**	**152.2**
M025	4.98	1209.1	713.9	1209.8	495.9	2.438	2.539	4.0	14.2	82	152.1
M026	4.98	1207.8	714.7	1208.6	493.9	2.445	2.539	3.7	14.0	84	152.6
M027	4.98	1205.5	708.3	1205.8	497.5	2.423	2.539	4.6	14.8	79	151.2
M028	4.98	1209.0	717.5	1209.3	491.8	2.458	2.539	3.2	13.5	87	153.4
M029	4.98	1203.4	708.4	1203.7	495.3	2.430	2.539	4.3	14.5	80	151.6
M030						specimen damaged					
Average	**4.98**	**1207.0**	**712.6**	**1207.4**	**494.9**	**2.439**	**2.539**	**3.9**	**14.2**	**83**	**152.2**
M031	7.18	1180.5	692.2	1180.9	488.7	2.416	2.456	1.6	17.0	98	150.7
M032						specimen damaged					
M033	7.18	1187.7	696.8	1187.8	491.0	2.419	2.456	1.5	16.9	99	150.9
M034	7.18	1177.3	691.0	1177.3	486.3	2.421	2.456	1.4	16.8	100	151.1
M035	7.18	1176.6	689.2	1176.9	487.7	2.413	2.456	1.8	17.1	98	150.5
M036	7.18	1180.7	693.2	1180.9	487.7	2.421	2.456	1.4	16.8	100	151.1
Average	**7.18**	**1180.6**	**692.5**	**1180.8**	**488.3**	**2.418**	**2.456**	**1.6**	**16.9**	**99**	**150.9**
M037	4.99	1208.5	713.4	1208.8	495.4	2.439	2.538	3.9	14.2	83	152.2
M038	4.99	1215.9	719.1	1216.3	497.2	2.445	2.538	3.6	14.0	84	152.6
M039	4.99	1215.1	720.8	1215.3	494.5	2.457	2.538	3.2	13.6	87	153.3
M040	4.99	1211.8	720.1	1212.1	492.0	2.463	2.538	2.9	13.4	89	153.7
M041	4.99	1217.4	721.5	1217.5	496.0	2.454	2.538	3.3	13.7	86	153.2
M042	4.99	1205.3	712.2	1205.6	493.4	2.443	2.538	3.7	14.1	84	152.4
Average	**4.99**	**1212.3**	**717.9**	**1212.6**	**494.8**	**2.450**	**2.538**	**3.4**	**13.8**	**85**	**152.9**
M043	4.90	1218.5	720.7	1218.9	498.2	2.446	2.542	3.8	13.9	83	152.6
M044	4.90	1211.2	714.2	1211.5	497.3	2.436	2.542	4.2	14.3	81	152.0
M045	4.90	1209.3	718.1	1209.7	491.6	2.460	2.542	3.2	13.4	87	153.5
M046	4.90	1211.0	718.1	1211.2	493.1	2.456	2.542	3.4	13.5	86	153.2
M047	4.90	1198.8	707.9	1199.0	491.1	2.441	2.542	4.0	14.1	82	152.3
M048	4.90	1203.0	714.1	1203.2	489.1	2.460	2.542	3.2	13.4	87	153.5
Average	**4.90**	**1208.6**	**715.5**	**1208.9**	**493.4**	**2.450**	**2.542**	**3.6**	**13.8**	**84**	**152.9**
M049	5.02	1207.4	714.3	1207.7	493.4	2.447	2.537	3.5	14.0	85	152.7
M050	5.02	1206.2	713.1	1206.4	493.3	2.445	2.537	3.6	14.0	84	152.6
M051	5.02	1205.6	717.1	1205.9	488.8	2.466	2.537	2.8	13.3	90	153.9
M052	5.02	1211.6	720.8	1211.9	491.1	2.467	2.537	2.8	13.3	90	153.9
M053	5.02	1206.5	713.9	1206.6	492.7	2.449	2.537	3.5	13.9	85	152.8
M054	5.02	1206.5	717.5	1206.6	489.1	2.467	2.537	2.8	13.3	90	153.9
Average	**5.02**	**1207.3**	**716.1**	**1207.5**	**491.4**	**2.457**	**2.537**	**3.2**	**13.6**	**87**	**153.3**

Table A2. March Air Reserve Base SGC data.

Specimen No.	Binder Content (%)	Sample Mass (g) Dry	In Water	SSD	Volume (cc)	Specific Gravity Actual	Theoretical	Air Voids (%)	VMA (%)	% Voids Filled	Unit Weight (lb/ft^3)
G001	4.74	4718.0	2736.6	4729.4	1992.8	2.368	2.549	7.1	16.5	66	147.7
G002	4.74	4714.2	2738.8	4719.0	1980.2	2.381	2.549	6.6	16.0	68	148.6
G003	4.74	4726.5	2754.5	4733.0	1978.5	2.389	2.549	6.3	15.8	69	149.1
G004	4.74	4725.1	2750.3	4733.0	1982.7	2.383	2.549	6.5	16.0	68	148.7
G005	4.74	4719.4	2749.1	4729.2	1980.1	2.383	2.549	6.5	16.0	68	148.7
G006	4.74	4720.2	2748.5	4733.3	1984.8	2.378	2.549	6.7	16.1	67	148.4
Average	**4.74**	**4720.6**	**2746.3**	**4729.5**	**1983.2**	**2.380**	**2.549**	**6.6**	**16.1**	**68**	**148.5**
G007	5.27	4745.7	2766.7	4749.2	1982.5	2.394	2.528	5.3	16.1	76	149.4
G008	5.27	4736.2	2756.5	4739.3	1982.8	2.389	2.528	5.5	16.2	75	149.1
G009	5.27	4747.6	2788.5	4750.1	1961.6	2.420	2.528	4.3	15.1	81	151.0
G010	5.27	4749.1	2791.2	4755.7	1964.5	2.417	2.528	4.4	15.2	81	150.8
G011	5.27	4745.0	2794.6	4747.0	1952.4	2.430	2.528	3.9	14.8	84	151.7
G012	5.27	4745.8	2809.4	4748.1	1938.7	2.448	2.528	3.2	14.2	88	152.8
Average	**5.27**	**4744.9**	**2784.5**	**4748.2**	**1963.8**	**2.419**	**2.528**	**4.3**	**15.2**	**81**	**150.9**
G013	5.18	4751.8	2779.5	4754.6	1975.1	2.406	2.531	4.9	15.6	77	150.1
G014	5.18	4760.1	2785.0	4763.6	1978.6	2.406	2.531	4.9	15.6	77	150.1
G015	5.18	4757.1	2785.0	4759.7	1974.7	2.409	2.531	4.8	15.4	78	150.3
G016	5.18	4751.0	2780.0	4755.3	1975.3	2.405	2.531	5.0	15.6	77	150.1
G017	5.18	4760.3	2782.0	4765.7	1983.7	2.400	2.531	5.2	15.8	76	149.7
G018	5.18	4769.5	2790.4	4774.4	1984.0	2.404	2.531	5.0	15.6	77	150.0
Average	**5.18**	**4758.3**	**2783.7**	**4762.2**	**1978.6**	**2.405**	**2.531**	**5.0**	**15.6**	**77**	**150.1**
G019	5.18	4735.5	2744.1	4741.4	1997.3	2.371	2.531	6.3	16.8	71	147.9
G020	5.18	4744.3	2759.6	4748.8	1989.2	2.385	2.531	5.8	16.3	73	148.8
G021	5.18	4816.6	2818.4	4819.7	2001.3	2.407	2.531	4.9	15.5	78	150.2
G022	5.18	4764.6	2784.5	4767.8	1983.3	2.402	2.531	5.1	15.7	77	149.9
G023	5.18	4825.1	2837.6	4827.4	1989.8	2.425	2.531	4.2	14.9	81	151.3
G024	5.18	4747.2	2791.2	4749.7	1958.5	2.424	2.531	4.2	14.9	81	151.3
Average	**5.18**	**4772.2**	**2789.2**	**4775.8**	**1986.6**	**2.405**	**2.531**	**5.0**	**15.6**	**77**	**150.0**
G025	4.98	4755.0	2757.4	4761.3	2003.9	2.373	2.539	6.5	16.5	69	148.1
G026	4.98	4763.1	2763.4	4767.5	2004.1	2.377	2.539	6.4	16.4	70	148.3
G027	4.98	4772.4	2773.0	4779.4	2006.4	2.379	2.539	6.3	16.3	70	148.4
G028	4.98	4762.5	2763.7	4769.0	2005.3	2.375	2.539	6.5	16.5	69	148.2
G029	4.98	4746.9	2754.4	4752.0	1997.6	2.376	2.539	6.4	16.4	70	148.3
G030	4.98	4799.8	2791.0	4804.1	2013.1	2.384	2.539	6.1	16.1	71	148.8
Average	**4.98**	**4766.6**	**2767.2**	**4772.2**	**2005.1**	**2.377**	**2.539**	**6.4**	**16.4**	**70**	**148.3**
G031	7.18	4712.4	2777.5	4713.5	1936.0	2.434	2.456	0.9	16.4	103	151.9
G032	7.18	4742.5	2787.2	4744.0	1956.8	2.424	2.456	1.3	16.7	100	151.2
G033	7.18	4756.3	2798.2	4757.5	1959.3	2.428	2.456	1.2	16.6	101	151.5
G034	7.18	4761.5	2806.0	4762.5	1956.5	2.434	2.456	0.9	16.4	103	151.9
G035	7.18	4742.4	2770.6	4744.1	1973.5	2.403	2.456	2.2	17.5	95	149.9
G036					specimen damaged						
Average	**7.18**	**4743.0**	**2787.9**	**4744.3**	**1956.4**	**2.424**	**2.456**	**1.3**	**16.7**	**101**	**151.3**
G037	4.99	4732.0	2737.9	4740.6	2002.7	2.363	2.538	6.9	16.9	67	147.4
G038	4.99	4783.0	2766.0	4791.4	2025.4	2.362	2.538	6.9	16.9	67	147.4
G039	4.99	4751.3	2768.4	4755.8	1987.4	2.391	2.538	5.8	15.9	72	149.2
G040	4.99	4775.9	2793.7	4778.7	1985.0	2.406	2.538	5.2	15.4	75	150.1
G041	4.99	4791.8	2816.0	4793.1	1977.1	2.424	2.538	4.5	14.8	79	151.2
G042	4.99	4759.6	2794.6	4761.5	1966.9	2.420	2.538	4.6	14.9	78	151.0
Average	**4.99**	**4765.6**	**2779.4**	**4770.2**	**1990.8**	**2.398**	**2.538**	**5.5**	**15.6**	**74**	**149.7**
G043	4.90	4767.2	2788.2	4770.7	1982.5	2.405	2.542	5.4	15.3	74	150.0
G044	4.90	4748.6	2814.5	4802.0	1987.5	2.389	2.542	6.0	15.9	71	149.1
G045	4.90	4802.9	2813.9	4806.0	1992.1	2.411	2.542	5.2	15.1	75	150.4
G046	4.90	4807.4	2820.7	4811.4	1990.7	2.415	2.542	5.0	15.0	76	150.7
G047	4.90	4790.1	2808.8	4793.1	1984.3	2.414	2.542	5.0	15.0	76	150.6
G048	4.90	4798.8	2813.6	4803.7	1990.1	2.411	2.542	5.1	15.1	75	150.5
Average	**4.90**	**4785.8**	**2810.0**	**4797.8**	**1987.9**	**2.408**	**2.542**	**5.3**	**15.2**	**75**	**150.2**
G049	5.02	4767.3	2793.1	4769.6	1976.5	2.412	2.537	4.9	15.2	77	150.5
G050	5.02	4809.8	2825.2	4811.7	1986.5	2.421	2.537	4.6	14.9	79	151.1
G051	5.02	4799.6	2794.8	4802.3	2007.5	2.391	2.537	5.8	15.9	73	149.2
G052	5.02	4778.9	2786.4	4782.4	1996.0	2.394	2.537	5.6	15.8	73	149.4
G053	5.02	4832.3	2851.4	4834.2	1982.8	2.437	2.537	3.9	14.3	83	152.1
G054	5.02	4810.3	2836.7	4811.6	1974.9	2.436	2.537	4.0	14.4	82	152.0
Average	**5.02**	**4799.7**	**2814.6**	**4802.0**	**1987.4**	**2.417**	**2.537**	**4.7**	**15.0**	**78**	**150.8**

Table A3. Monroe County Marshall data.

Specimen No.	Binder Content (%)	Sample Mass (g)			Volume (cc)	Specific Gravity		Air Voids (%)	VMA (%)	% Voids Filled	Unit Weight (lb/ft^3)
		Dry	In Water	SSD		Actual	Theoretical				
M101	5.75	1198.7	672.2	1199.7	527.5	2.272	2.372	4.2	14.2	70	141.8
M102	5.75	1229.3	691.6	1230.1	538.5	2.283	2.372	3.8	13.8	73	142.4
M103	5.75	1214.0	686.3	1214.6	528.3	2.298	2.372	3.1	13.2	76	143.4
M104	5.75	1215.0	689.3	1215.6	526.3	2.309	2.372	2.7	12.8	79	144.1
M105	5.75	1228.9	695.9	1229.5	533.6	2.303	2.372	2.9	13.0	78	143.7
M106	5.75	1231.9	699.1	1232.5	533.4	2.310	2.372	2.6	12.8	79	144.1
Average						**2.296**	**2.372**	**3.2**	**13.3**	**76**	**143.3**
M107	5.60	1174.1	660.2	1175.0	514.8	2.281	2.377	4.1	13.7	70	142.3
M108	5.60	1177.8	663.1	1178.7	515.6	2.284	2.377	3.9	13.6	71	142.5
M109	5.60	1172.8	658.2	1173.6	515.4	2.276	2.377	4.3	13.9	69	142.0
M110	5.60	1186.3	669.1	1187.0	517.9	2.291	2.377	3.6	13.4	73	142.9
M111	5.60	1174.6	662.3	1175.2	512.9	2.290	2.377	3.7	13.4	73	142.9
M112	5.60	1171.0	660.6	1171.6	511.0	2.292	2.377	3.6	13.3	73	143.0
Average						**2.285**	**2.377**	**3.9**	**13.5**	**72**	**142.6**
M113	5.73	1178.3	664.7	1179.0	514.3	2.291	2.373	3.5	13.5	74	143.0
M114	5.73	1173.7	660.2	1174.5	514.3	2.282	2.373	3.8	13.8	72	142.4
M115	5.73	1193.2	674.7	1193.7	519.0	2.299	2.373	3.1	13.2	76	143.5
M116	5.73	1170.8	661.6	1171.4	509.8	2.297	2.373	3.2	13.2	76	143.3
M117	5.73	1164.8	660.5	1165.6	505.1	2.306	2.373	2.8	12.9	78	143.9
M118	5.73	1176.5	667.7	1176.8	509.1	2.311	2.373	2.6	12.7	79	144.2
Average						**2.298**	**2.373**	**3.2**	**13.2**	**76**	**143.4**
M119	5.87	1187.9	675.5	1188.6	513.1	2.315	2.369	2.3	12.7	82	144.5
M120	5.87	1168.1	662.9	1168.7	505.8	2.309	2.369	2.5	12.9	81	144.1
M121	5.87	1175.6	669.4	1175.9	506.5	2.321	2.369	2.0	12.5	84	144.8
M122	5.87	1167.1	663.6	1167.6	504.0	2.316	2.369	2.2	12.7	82	144.5
M123	5.87	1166.4	664.6	1166.7	502.1	2.323	2.369	1.9	12.4	84	145.0
M124	5.87	1167.3	664.1	1167.6	503.5	2.318	2.369	2.1	12.6	83	144.7
Average						**2.317**	**2.369**	**2.2**	**12.6**	**83**	**144.6**
M125	5.87	1159.8	653.9	1160.8	506.9	2.288	2.369	3.4	13.7	75	142.8
M126	5.87	1182.2	665.1	1183.2	518.1	2.282	2.369	3.7	13.9	74	142.4
M127	5.87	1178.6	663.0	1179.2	516.2	2.283	2.369	3.6	13.9	74	142.5
M128	5.87	1174.0	658.6	1174.7	516.1	2.275	2.369	4.0	14.2	72	141.9
M129	5.87	1181.2	665.5	1181.8	516.3	2.288	2.369	3.4	13.7	75	142.8
M130	5.87	1184.50	666.70	1185.20	518.50	2.28	2.37	3.55	13.83	74.35	142.55
Average						**2.283**	**2.369**	**3.6**	**13.9**	**74**	**142.5**
M131	5.65	1134.8	642.9	1135.3	492.4	2.305	2.376	3.0	12.9	77	143.8
M132	5.65	1169.60	661.70	1170.20	508.50	2.30	2.38	3.18	13.04	75.62	143.53
M133	5.65	1158.1	656.9	1158.8	501.9	2.307	2.376	2.9	12.8	78	144.0
M134	5.65	1155.6	653.0	1156.3	503.3	2.296	2.376	3.3	13.2	75	143.3
M135	5.65	1131.0	642.2	1131.6	489.4	2.311	2.376	2.7	12.6	78	144.2
M136	5.65	1139.4	648.0	1139.9	491.9	2.316	2.376	2.5	12.4	80	144.5
Average						**2.306**	**2.376**	**2.9**	**12.8**	**77**	**143.9**

Table A4. Monroe County SGC data.

Specimen No.	Binder Content (%)	Sample Mass (g)			Volume (cc)	Specific Gravity		Air Voids (%)	VMA (%)	% Voids Filled	Unit Weight (lb/ft^3)
		Dry	In Water	SSD		Actual	Theoretical				
G101	5.75	4536.1	2568.6	4537.8	1969.2	2.304	2.372	2.9	13.0	78	143.7
G102	5.75	4548.5	2574.7	4550.3	1975.6	2.302	2.372	3.0	13.0	77	143.7
G103	5.75	4523.6	2561.1	4525.2	1964.1	2.303	2.372	2.9	13.0	78	143.7
G104	5.75	4549.0	2574.6	4551.2	1976.6	2.301	2.372	3.0	13.1	77	143.6
G105	5.75	4552.1	2572.5	4553.9	1981.4	2.297	2.372	3.2	13.2	76	143.4
G106	5.75	4566.6	2584.0	4568.9	1984.9	2.301	2.372	3.0	13.1	77	143.6
Average						**2.301**		**3.0**	**13.1**	**77**	**143.6**
G107	5.60	4549.6	2540.9	4555.2	2014.3	2.259	2.377	5.0	14.6	66	140.9
G108	5.60	4528.8	2529.9	4531.4	2001.5	2.263	2.377	4.8	14.4	67	141.2
G109	5.60	4544.6	2558.6	4546.6	1988.0	2.286	2.377	3.8	13.5	72	142.6
G110	5.60	4550.0	2558.8	4552.8	1994.0	2.282	2.377	4.0	13.7	71	142.4
G111	5.60	4551.4	2571.3	4553.0	1981.7	2.297	2.377	3.4	13.1	74	143.3
G112	5.60	4560.8	2579.6	4562.8	1983.2	2.300	2.377	3.3	13.0	75	143.5
Average						**2.284**	**2.377**	**3.9**	**13.6**	**71**	**142.5**
G113	5.73	4565.2	2561.3	4568.2	2006.9	2.275	2.373	4.1	14.1	71	141.9
G114	5.73	4546.2	2558.8	4549.2	1990.4	2.284	2.373	3.7	13.7	73	142.5
G115	5.73	4581.8	2573.8	4585.0	2011.2	2.278	2.373	4.0	13.9	71	142.2
G116	5.73	4560.8	2565.4	4564.6	1999.2	2.281	2.373	3.9	13.8	72	142.4
G117	5.73	4580.4	2581.2	4583.4	2002.2	2.288	2.373	3.6	13.6	74	142.8
G118	5.73	4559.2	2565.6	4561.4	1995.8	2.284	2.373	3.7	13.7	73	142.5
Average						**2.282**	**2.373**	**3.8**	**13.8**	**72**	**142.4**
G119	5.87	4556.6	2547.8	4561.6	2013.8	2.263	2.369	4.5	14.7	70	141.2
G120	5.87	4543.0	2543.5	4546.8	2003.3	2.268	2.369	4.3	14.5	71	141.5
G121	5.87	4550.6	2564.2	4553.8	1989.6	2.287	2.369	3.4	13.7	75	142.7
G122	5.87					specimen damaged					
G123	5.87	4568.8	2598.8	4570.8	1972.0	2.317	2.369	2.2	12.6	83	144.6
G124	5.87	4554.2	2585.3	4557.0	1971.7	2.310	2.369	2.5	12.9	81	144.1
Average						**2.289**	**2.369**	**3.4**	**13.7**	**76**	**142.8**
G125	5.87	4547.6	2548.2	4550.2	2002.0	2.272	2.369	4.1	14.3	71	141.7
G126	5.87	4542.0	2550.2	4545.0	1994.8	2.277	2.369	3.9	14.1	73	142.1
G127	5.87	4560.2	2556.1	4564.4	2008.3	2.271	2.369	4.1	14.4	71	141.7
G128	5.87	4561.4	2557.2	4567.2	2010.0	2.269	2.369	4.2	14.4	71	141.6
G129	5.87	4571.2	2561.2	4575.4	2014.2	2.269	2.369	4.2	14.4	71	141.6
G130	5.87	4562.0	2555.0	4565.0	2010.0	2.270	2.369	4.2	14.4	71	141.6
Average						**2.271**	**2.369**	**4.1**	**14.3**	**71**	**141.7**
G131	5.65	4563.4	2543.5	4567.2	2023.7	2.255	2.376	5.1	14.7	66	140.7
G132	5.65	4539.4	2541.5	4544.6	2003.1	2.266	2.376	4.6	14.3	68	141.4
G133	5.65	4548.6	2566.5	4550.4	1983.9	2.293	2.376	3.5	13.3	74	143.1
G134	5.65	4561.2	2577.2	4563.4	1986.2	2.296	2.376	3.3	13.2	75	143.3
G135	5.65	4553.0	2581.7	4555.2	1973.5	2.307	2.376	2.9	12.8	77	144.0
G136	5.65	4553.60	2581.50	4555.60	1974.10	2.31	2.38	2.90	12.79	77.31	143.94
Average						**2.283**	**2.376**	**3.4**	**13.7**	**72**	**142.5**

Table A5. Columbus Air Force Base surface mix Marshall data.

Specimen No.	Binder Content (%)	Sample Mass (g)			Volume (cc)	Specific Gravity		Air Voids (%)	VMA (%)	% Voids Filled	Unit Weight (lb/ft^3)
		Dry	In Water	SSD		Actual	Theoretical				
M207	5.69	1185.6	669.3	1185.9	516.6	2.295	2.374	3.3	12.9	74	143.2
M208	5.69	1189.0	671.9	1189.2	517.3	2.298	2.374	3.2	12.8	75	143.4
M209	5.69	1185.6	670.1	1185.9	515.8	2.299	2.374	3.2	12.8	75	143.4
M210	5.69	1190.7	672.1	1191.1	519.0	2.294	2.374	3.4	12.9	74	143.2
M211	5.69	1196.0	673.5	1196.3	522.8	2.288	2.374	3.6	13.2	72	142.8
M212	5.69	1192.2	672.3	1192.5	520.2	2.292	2.374	3.5	13.0	73	143.0
Average						**2.294**	**2.374**	**3.4**	**12.9**	**74**	**143.2**
M213	5.83	1197.8	676.1	1198.5	522.4	2.293	2.370	3.2	13.1	75	143.1
M214	5.83	1197.1	669.0	1197.3	528.3	2.266	2.370	4.4	14.1	69	141.4
M215	5.83	1195.8	669.4	1196.7	527.3	2.268	2.370	4.3	14.1	69	141.5
M216	5.83	1199.5	675.8	1200.4	524.6	2.287	2.370	3.5	13.4	74	142.7
M217	5.83	1193.5	671.5	1194.1	522.6	2.284	2.370	3.6	13.5	73	142.5
M218	5.83	1196.1	671.3	1196.2	524.9	2.279	2.370	3.8	13.7	72	142.2
Average						**2.279**	**2.370**	**3.8**	**13.6**	**72**	**142.2**
M219	5.78	1172.9	660.6	1173.2	512.6	2.288	2.371	3.5	13.3	74	142.8
M220	5.78	1195.9	675.6	1196.2	520.6	2.297	2.371	3.1	12.9	76	143.3
M221	5.78	1186.5	670.7	1186.7	516.0	2.299	2.371	3.0	12.8	76	143.5
M222	5.78	1184.8	669.2	1185.3	516.1	2.296	2.371	3.2	13.0	75	143.3
M223	5.78	964.3	543.3	964.5	421.2	2.289	2.371	3.5	13.2	74	142.9
M224	5.78	1176.4	660.6	1176.5	515.9	2.280	2.371	3.8	13.6	72	142.3
Average						**2.292**	**2.371**	**3.4**	**13.1**	**74**	**143.0**
M237	5.53	1182.0	660.2	1183.8	523.6	2.257	2.379	5.1	14.2	64	140.9
M238	5.53	1179.1	659.3	1180.8	521.5	2.261	2.379	5.0	14.1	65	141.1
M239	5.53	1183.6	662.4	1185.0	522.6	2.265	2.379	4.8	13.9	65	141.3
M240	5.53	1179.1	661.6	1180.0	518.4	2.274	2.379	4.4	13.5	67	141.9
M241	5.53	1178.9	656.6	1180.1	523.5	2.252	2.379	5.4	14.4	63	140.5
M242	5.53	1177.5	658.4	1178.6	520.2	2.264	2.379	4.9	14.0	65	141.2
Average						**2.262**	**2.379**	**4.9**	**14.0**	**65**	**141.2**
M243	5.50	1176.5	665.6	1177.3	511.7	2.299	2.371	3.0	12.6	76	143.5
M244	5.50	1170.6	658.2	1171.5	513.3	2.281	2.371	3.8	13.3	71	142.3
M245	5.50	1176.9	664.2	1177.7	513.5	2.292	2.371	3.3	12.9	74	143.0
M246	5.50	1180.4	667.0	1181.1	514.1	2.296	2.371	3.1	12.7	75	143.3
M247	5.50	1163.3	656.7	1163.8	507.1	2.294	2.371	3.2	12.8	75	143.1
M248	5.50	1180.70	665.40	1181.30	515.90	2.29	2.37	3.46	12.98	73.36	142.81
Average						**2.292**	**2.371**	**3.3**	**12.9**	**74**	**143.0**
M249	5.47	1176.9	663.9	1177.5	513.6	2.291	2.381	3.8	12.8	71	143.0
M250	5.47	1179.60	664.10	1180.70	516.60	2.28	2.38	4.12	13.15	68.70	142.48
M251	5.47	1158.4	652.3	1158.9	506.6	2.287	2.381	4.0	13.0	69	142.7
M252	5.47	1172.0	658.0	1172.8	514.8	2.277	2.381	4.4	13.4	67	142.1
M253	5.47	1170.7	658.1	1171.2	513.1	2.282	2.381	4.2	13.2	68	142.4
M254	5.47	1168.7	654.7	1169.2	514.5	2.272	2.381	4.6	13.6	66	141.7
Average						**2.282**	**2.381**	**4.2**	**13.2**	**68**	**142.4**

Table A6. Columbus Air Force Base surface mix SGC data.

Specimen No.	Binder Content (%)	Sample Mass (g)			Volume (cc)	Specific Gravity		Air Voids (%)	VMA (%)	% Voids Filled	Unit Weight (lb/ft^3)
		Dry	In Water	SSD		Actual	Theoretical				
G207	5.69	4516.3	2532.1	4519.7	1987.6	2.272	2.374	4.3	13.8	69	141.8
G208	5.69	4516.3	2535.6	4519.1	1983.5	2.277	2.374	4.1	13.6	70	142.1
G209	5.69	4531.3	2542.5	4532.4	1989.9	2.277	2.374	4.1	13.6	70	142.1
G210	5.69	4545.2	2556.4	4546.9	1990.5	2.283	2.374	3.8	13.4	71	142.5
G211	5.69	4559.2	2561.5	4561.1	1999.6	2.280	2.374	4.0	13.5	71	142.3
G212	5.69	4550.2	2558.4	4552.2	1993.8	2.282	2.374	3.9	13.4	71	142.4
Average						**2.279**		**4.0**	**13.5**	**70**	**142.2**
G213	5.83	4545.4	2528.4	4552.3	2023.9	2.246	2.370	5.2	14.9	65	140.1
G214	5.83	4519.3	2515.8	4523.8	2008.0	2.251	2.370	5.0	14.7	66	140.4
G215	5.83	4528.0	2535.9	4532.4	1996.5	2.268	2.370	4.3	14.1	69	141.5
G216	5.83	4537.8	2544.5	4542.2	1997.7	2.272	2.370	4.1	13.9	70	141.7
G217	5.83	4538.8	2548.1	4541.8	1993.7	2.277	2.370	3.9	13.7	71	142.1
G218	5.83	4527.9	2550.6	4531.0	1980.4	2.286	2.370	3.5	13.4	74	142.7
Average						**2.270**	**2.370**	**4.2**	**14.0**	**70**	**141.6**
G219	5.78	4545.2	2549.8	4548.1	1998.3	2.275	2.371	4.1	13.8	70	141.9
G220	5.78	4549.9	2556.6	4552.4	1995.8	2.280	2.371	3.9	13.6	72	142.3
G221	5.78	4534.8	2546.3	4537.3	1991.0	2.278	2.371	4.0	13.7	71	142.1
G222	5.78	4562.2	2560.0	4564.6	2004.6	2.276	2.371	4.0	13.7	71	142.0
G223	5.78	4545.6	2551.8	4548.4	1996.6	2.277	2.371	4.0	13.7	71	142.1
G224	5.78	4548.0	2553.0	4550.3	1997.3	2.277	2.371	4.0	13.7	71	142.1
Average						**2.277**	**2.371**	**4.0**	**13.7**	**71**	**142.1**
G237	5.53	4355.5	2407.9	4366.5	1958.6	2.224	2.379	6.5	15.5	58	138.8
G238	5.53	4479.9	2490.6	4487.5	1996.9	2.243	2.379	5.7	14.7	61	140.0
G239	5.53	4505.4	2509.2	4514.6	2005.4	2.247	2.379	5.6	14.6	62	140.2
G240	5.53	4505.4	2508.9	4514.4	2005.5	2.247	2.379	5.6	14.6	62	140.2
G241	5.53	4502.3	2510.0	4509.9	1999.9	2.251	2.379	5.4	14.4	63	140.5
G242	5.53	4519.8	2517.0	4532.1	2015.1	2.243	2.379	5.7	14.7	61	140.0
Average						**2.247**	**2.379**	**5.6**	**14.6**	**62**	**140.2**
G243	5.50	4519.5	2494.7	4534.8	2040.1	2.215	2.371	6.6	15.8	58	138.2
G244	5.50	4539.6	2511.5	4553.9	2042.4	2.223	2.371	6.2	15.5	60	138.7
G245	5.50	4537.9	2525.1	4549.5	2024.4	2.242	2.371	5.4	14.8	63	139.9
G246	5.50	4563.4	2536.5	4570.6	2034.1	2.243	2.371	5.4	14.7	64	140.0
G247	5.50	4517.6	2524.9	4522.2	1997.3	2.262	2.371	4.6	14.0	67	141.1
G248	5.50	4568.5	2549.9	4575.8	2025.9	2.255	2.371	4.9	14.3	66	140.7
Average						**2.240**	**2.371**	**5.4**	**14.8**	**63**	**139.8**
G249	5.47	4542.3	2531.2	4547.3	2016.1	2.253	2.381	5.4	14.3	62	140.6
G250	5.47	4554.9	2538.8	4561.5	2022.7	2.252	2.381	5.4	14.4	62	140.5
G251	5.47	4569.1	2546.9	4575.5	2028.6	2.252	2.381	5.4	14.3	62	140.5
G252	5.47	4562.0	2545.1	4568.7	2023.6	2.254	2.381	5.3	14.3	63	140.7
G253	5.47	4531.7	2525.7	4537.3	2011.6	2.253	2.381	5.4	14.3	62	140.6
G254	5.47	4551.10	2533.90	4556.60	2022.70	2.25	2.38	5.52	14.42	61.74	140.40
Average						**2.252**	**2.381**	**5.4**	**14.3**	**62**	**140.6**

Table A7. Columbus Air Force Base asphalt base mix Marshall data.

Specimen No.	Binder Content (%)	Sample Mass (g)			Volume (cc)	Specific Gravity		Air Voids (%)	VMA (%)	% Voids Filled	Unit Weight (lb/ft^3)
		Dry	In Water	SSD		Actual	Theoretical				
M201	5.79	1181.1	654.4	1182.0	527.6	2.239	2.371	5.6	15.1	63	139.7
M202	5.79	1173.1	650.2	1174.1	523.9	2.239	2.371	5.6	15.1	63	139.7
M203	5.79	1172.0	646.3	1173.3	527.0	2.224	2.371	6.2	15.7	60	138.8
M204	5.79	1173.2	653.1	1174.3	521.2	2.251	2.371	5.1	14.7	65	140.5
M205	5.79	1170.4	649.8	1171.6	521.8	2.243	2.371	5.4	15.0	64	140.0
M206	5.79	1167.8	651.6	1168.1	516.5	2.261	2.371	4.6	14.3	68	141.1
Average						**2.243**	**2.371**	**5.4**	**15.0**	**64**	**139.9**
M225	5.80	1203.8	679.1	1204.4	525.3	2.292	2.371	3.3	13.1	75	143.0
M226	5.80	1205.3	677.9	1206.0	528.1	2.282	2.371	3.7	13.5	72	142.4
M227	5.80	1174.8	662.6	1175.8	513.2	2.289	2.371	3.4	13.2	74	142.8
M228	5.80	1189.4	668.9	1190.3	521.4	2.281	2.371	3.8	13.5	72	142.3
M229	5.80	1185.7	667.6	1186.6	519.0	2.285	2.371	3.6	13.4	73	142.6
M230	5.80	1174.7	658.3	1175.7	517.4	2.270	2.371	4.2	14.0	70	141.7
Average						**2.283**	**2.371**	**3.7**	**13.5**	**73**	**142.5**
M231	5.92	1198.3	667.0	1198.7	531.7	2.254	2.367	4.8	14.7	67	140.6
M232	5.92	1161.9	648.0	1163.1	515.1	2.256	2.367	4.7	14.6	68	140.8
M233	5.92	1344.9	749.1	1345.5	596.4	2.255	2.367	4.7	14.6	68	140.7
M234	5.92	1204.8	671.6	1205.4	533.8	2.257	2.367	4.6	14.6	68	140.8
M235	5.92	1197.3	667.4	1198.6	531.2	2.254	2.367	4.8	14.7	68	140.6
M236	5.92	1199.5	664.2	1200.4	536.2	2.237	2.367	5.5	15.3	64	139.6
Average						**2.252**	**2.367**	**4.9**	**14.8**	**67**	**140.5**

Table A8. Columbus Air Force Base asphalt base mix SGC data.

Specimen No.	Binder Content (%)	Sample Mass (g)			Volume (cc)	Specific Gravity		Air Voids (%)	VMA (%)	% Voids Filled	Unit Weight (lb/ft^3)
		Dry	In Water	SSD		Actual	Theoretical				
G201	5.79	4541.5	2534.8	4545.4	2010.6	2.259	2.371	4.7	14.4	67	140.9
G202	5.79	4556.9	2548.6	4559.2	2010.6	2.266	2.371	4.4	14.1	69	141.4
G203	5.79	4558.2	2549.8	4562.8	2013.0	2.264	2.371	4.5	14.2	68	141.3
G204	5.79	4536.0	2532.4	4540.0	2007.6	2.259	2.371	4.7	14.4	67	141.0
G205	5.79	4564.6	2554.2	4567.5	2013.3	2.267	2.371	4.4	14.1	69	141.5
G206	5.79	4580.3	2561.0	4583.6	2022.6	2.265	2.371	4.5	14.2	68	141.3
Average						**2.263**		**4.5**	**14.2**	**68**	**141.2**
G225	5.80	4518.5	2519.8	4525.5	2005.7	2.253	2.371	5.0	14.6	66	140.6
G226	5.80	4530.1	2524.6	4535.0	2010.4	2.253	2.371	5.0	14.6	66	140.6
G227	5.80	4527.2	2540.2	4527.7	1987.5	2.278	2.371	3.9	13.7	71	142.1
G228	5.80	4534.7	2546.3	4540.5	1994.2	2.274	2.371	4.1	13.8	70	141.9
G229	5.80	4524.0	2551.5	4526.9	1975.4	2.290	2.371	3.4	13.2	74	142.9
G230	5.80	4520.5	2548.1	4524.1	1976.0	2.288	2.371	3.5	13.3	74	142.8
Average						**2.276**	**2.371**	**4.0**	**13.7**	**71**	**142.0**
G231	5.92	4530.4	2516.4	4536.6	2020.2	2.243	2.367	5.3	15.1	65	139.9
G232	5.92	4524.8	2516.2	4531.6	2015.4	2.245	2.367	5.1	15.0	66	140.1
G233	5.92	4519.7	2512.0	4525.4	2013.4	2.245	2.367	5.2	15.0	66	140.1
G234	5.92	4529.3	2521.3	4534.5	2013.2	2.250	2.367	4.9	14.8	67	140.4
G235	5.92	4522.5	2516.8	4526.8	2010.0	2.250	2.367	4.9	14.8	67	140.4
G236	5.92	4531.1	2525.3	4537.0	2011.7	2.252	2.367	4.8	14.7	67	140.5
Average						**2.247**	**2.367**	**5.0**	**14.9**	**66**	**140.2**

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14. ABSTRACT

This report presents results from a field study to compare the density of asphalt concrete specimens compacted using the Marshall apparatus to the density of specimens compacted using the Superpave gyratory compactor (SGC). The purpose of the study was to determine if using a new alternative construction specification based on compaction with the SGC would produce a different density than the traditional specification based on compaction with the Marshall apparatus. In addition, laboratory tests to indicate asphalt mixture rutting potential were performed to develop guidance for using new methods to assess mixture quality. Six paving mixtures were sampled to compact specimens using 75 blows of the manual Marshall hammer and 75 gyrations of the SGC. Three of the mixtures had higher air voids contents when compacted with the SGC. Two had nearly equal air voids content, and one had lower air voids content. The standard deviation of air voids content for a group of specimens compacted using the SGC was typically less than half of that for specimens compacted using the manual Marshall hammer. Using the SGC to prepare specimens for quality control and quality assurance is not expected to change the payment to a contractor for a given quality of work when using the method described in UFGS 32-12-15, and is expected to produce adequate mixtures when designed by the alternative specification allowing its use.

15. SUBJECT TERMS
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